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A STUDY OF THE PERFORMANCE OF AN ASTRONAUT DURING INGRESS AND EGRESS MANEUVERS THROUGH AIRLOCKS AND PASSAGEWAYS

by Harry L. Loats, Jr., and William J. Bruchey, Jr.

Prepared by
ENVIRONMENTAL RESEARCH ASSOCIATES
Randallstown, Md.
for Langley Research Center

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Prepared under Contract No. NAS 1-4059 by
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Personnel of ENVIRONMENTAL RESEARCH ASSOCIATES who cooperated in this project and in preparation of this report include: G. Samuel Mattingly, Program Manager; C. E. Brush, Engineering; G. Hay, Test Subject; N. B. Tharp, Test Subject.

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1.0 ABSTRACT

The performance characteristics of a pressure-suited astronaut during ingress-egress through various geometry airlocks were studied by water immersion techniques. The buoyancy force induced by water displacement of a totally immersed subject was used to counteract all or part of his adjusted total weight to provide the desired simulated gravity level. The subject performed real-time maneuvers as determined from functional analysis of representative extravehicular and intravehicular tasks.

The purpose of this phase of the contract was to generate additional data on refined experiments initiated under previous contractual phases and to expand the experiment scope to include rescue, replenishment and general maneuvers exterior to the airlock. The effect of the variation of airlock dimension and shape on the capabilities to perform manual ingress-egress was evaluated by comparative time-task analysis. A series of demonstrations were performed to develop information for evaluation of future research areas such as rescue operations, the effects of sub-earth normal gravity levels, replenishment through airlocks and ability to produce torque forces.

2.0 INTRODUCTION

Planned NASA missions of longer and more complex durations and performance, increasingly require pre-assessment of the human factors aspects of hardware components and subsystems. One of the most important of these is the airlock. Previous missions such as Mercury and Gemini have not been configured to require airlocks. The advent of the AAP program and future programs as yet unspecified, with anticipated EVA programs require the investigation of the human factors aspects governing the utilization of airlocks.

With these future mission requirements in view, a water immersion simulation research program dealing with generalized airlock configurations was undertaken. Specifically addressed in this study were operating procedures, airlock ancillary hardware and the effects of volumetric and dimensional factors on such critical tasks as: ingress-egress, replenishment, rescue. Also investigated were important supporting functions such as manual torque capacity and the mobility of pressure suited astronauts.

The following report details the effort performed under Phase III of contract NAS1-4059, "Study of the Performance of an Astronaut During Ingress-Egress Maneuvers Through Spacecraft Airlocks and Passageways."

The work performed on NAS1-4059 was originally conceived to evaluate human performance in a 48" cylindrical airlock, designed by Environmental Research Associates on contract NAS1-2164, "A Study of Space Station Connections and Seals." The results of the study showed that existing sealing materials would be adequate for the purposes planned and that insufficient information existed on long-term vacuum effects on elastomers and seal re-useability in the space environment and on human factors aspects of airlock operation.

As an extension of NAS1-2164, Environmental Research Associates designed an airlock seal-test fixture for use in a vacuum test facility. This was configured as a 28.5 inch diameter, extending airlock tunnel and was built by the Norfolk Navy Yard and placed on test at Langley Research Center.

Since this represented a minimal airlock configuration for ingress-egress functions from a human factors viewpoint, a further continuation to NAS1-2164 was undertaken to design a seal-test fixture of adequate dimensions to serve as a general purpose airlock for one-man manual operations. This airlock permitted tests of a variety of seals in various door configurations which could be placed internal or external to the vacuum test chamber. The airlock was 48" in diameter by 72" long and contained an oval door at one end and a circular door at the other end and a pullout side hatch. A plastic mock-up of this airlock became the basic unit for the study of astronaut performance in contract NAS1-4059.

Phase I of NAS1-4059 was initiated in June, 1964, and constituted a pilot investigation to establish a valid simulation mode for the investigation of human capability to perform ingress-egress maneuvers. During Phase I, ERA subjects in United States Navy Mark IV-Mod 0 full pressure suits (FPS) performed ingress-egress maneuvers through the transparent airlock model. Initial tests were performed at normal earth gravity to determine baseline performance data. A second series of tests were conducted in a water immersion "weightless" simulation mode, in which the test subject was ballasted to achieve required neutral buoyancy. A final series of tests were conducted aboard the C-131B Zero Gravity Aircraft of the U. S. Air Force.

Motion picture photographs were taken during all test runs and an analytical evaluation was made by time-task-comparisons between the three simulation modes. The results of the comparisons, supported by subjective interpretation, indicated that the ingress-egress task in general was subject to task simulation and that the combined simulation modes of zero gravity aircraft and water immersion would be useful determinants of human capabilities.

Phase II of the contract was initiated in September, 1964 to conduct a series of experiments using the techniques developed in Phase I. Phase II demonstrated that significant differences existed between the simulated zero gravity ingress-egress and full gravity ingress-egress. In addition, Phase II evaluated the effect of the full pressure suit on astronauts' capabilities at a variety of pressure levels. Within this framework, more extensive quantitative data was gathered on ingress-egress problems and procedures utilizing the 48" by 72" airlock. The Phase II report included Phase I operations and was delivered in April, 1965. Phase III of NAS1-4059, was initiated in July, 1965. Its purpose was to generate additional quantitative data on refined experiments and to expand the experiment scope to include rescue, replenishment and general maneuvers exterior to the airlock. Evaluation of the astronaut's capabilities to conduct manual ingress-egress was made by comparative time-task analysis.

A series of demonstrations were performed to develop information for evaluation of future research areas such as rescue operations, the effects of sub-earth normal gravity levels, replenishment through airlocks and human ability to produce torque forces. This report covers the effort performed under Phase III of contract NAS1-4059.

3.0 WATER IMMERSION SIMULATION

The water immersion simulation technique employed in this experiment-study was developed by Environmental Research Associates during Phase I of this contract and comprises the complete submersion of a subject in an air-pressurized single-gas anthropomorphic FPS. The suit, the Navy Mark IV, Mod 0, Arrowhead version, is maintained at a pressure of 3.5 PSI above ambient by means of a relief valve mounted in the vent port of the suit.

The subject is maintained in a neutrally buoyant condition by means of distributed external weights, located to provide balance in roll, pitch, and yaw axes. The effects of pressure-gradient induced motion-instability is reduced by constraining task performance to a quasi-horizontal plane. This water immersion technique has been demonstrated to be valid for low-velocity motions within restricted areas such as airlocks by cross-correlation with similar task performance in the zero gravity aircraft. The subject is freed of external constraints by means of a self-contained breathing-gas pressurization unit. This unit uses a standard SCUBA air storage tank carried on the subject's back by means of a standard SCUBA backpack. Critical test components such as replenishment packages are balanced to neutral buoyancy in a similar fashion. For test at sub-earth normal gravity levels of 0.08 and 0.16 G a similar technique is employed except that appropriate extra-weight is added to accomplish a proper net negative buoyancy.

4.0 EXPERIMENT DESCRIPTION, PERFORMANCE AND RESULTS

4.1 OVERALL TASK DESCRIPTION

The general requirements for the number and description of the experiments to be performed under NAS1-4059, Phase III were determined a priori, and were specified in the contractural statement of work. In general, the experimental requirements called for the repetition of each task three times in succession at a specified simulated gravity level.

Table I is a summary of the tasks performed during the contract and specifies the simulated gravity level, airlock configuration and dimensions, subject replication and the report location of each task performed. Further, the table summarizes the performance of each task, identifying those tasks which were curtailed due to physical impossibility, or safety reasons. Task 1-2 and 2-2, normal and modified ingress-egress in simulated zero gravity employing the Air Force C-131B aircraft were eliminated at the option of the Government due to unavailability of the GFE aircraft.

The subjects to be investigated and demonstrated during this contractural phase are divided for convenience and similarity of performance characteristics into five categories, as follows:

- Ingress-Egress
- Rescue
- Replenishment
- Torque
- Exterior Maneuvers

The ancillary equipment employed in the various experiments and demonstrations is listed in Figure 4.1-1, which specifies the equipment used for each of the twenty-one tasks performed during this contractual phase.

TABLE I - TASK PERFORMANCE SUMMARY

Task No.		Task	G Level	Configuration	Diameter - Ft	Length - Ft	Subjects	Maneuvers	Location	Comments
1	1	IN	0	CY	4	6	2	3	4.2	
	2	IN	0	CY	4	6	1	3	-	Task not performed. NASA unable to supply GFE Aircraft for test.
2	1	IM	0	CY	4	6	2	3	4.2	
	2	IM	0	CY	4	6	1	3	-	Same as 1-2
3	1	TO	0	-	-	-	2	3	4.5	A
	2	TO	0	-	-	6	2	3	4.5	B
	2	TO	0	-	-	5	2	3	4.5	B
	2	TO	0	-	-	4	2	3	4.5	B
	3	TO	0	-	-	-	2	3	4.5	C
	4	TI	0	CY	4	6	2	3	4.5	A
	5	TI	0	CY	4	6	2	3	4.5	B
	6	TI	0	CY	4	6	2	3	4.5	C
	7	TO	1	-	-	-	2	3	4.5	A
	8	TO	1	-	-	-	2	3	4.5	B
4	1	CT	0	CY	4	6	2	3	4.4	SP
	2	CT	0	CY	4	6	2	3	4.4	CU
	3	CT	0	CY	4	6	2	3	4.4	CY
5	1	MA	0	CY	4	6	2	3	4.6	With aids.
	2	MA	0	CY	4	6	2	3	4.6	Without aids
6		R	0	CY	4	6	1	3	4.3	
7		IN	0	CY	4	4.5	2	3	4.2	Reduced lengths chosen by NASA Project Engineer
		IN	0	CY	4	3	2	3	4.2	
		IN	0	CY	4	15	2	3	4.2	

IN - Normal Ingress-Egress
IM - Modified Ingress-Egress
TI - Torque Inside Airlock
TO - Torque Outside Airlock
CT - Cargo Transfer
M - Maneuver about Airlock
PT - Personnel Transfer
R - Rescue

CY - Cylinder
SP - Sphere
CU - Cube
CP - Capsule
A - One hand in handle, one on bar, feet in stirrup
B - Two hands on bar, feet in stirrup
C - Two hands on bar, no foot-holds

TABLE I - TASK PERFORMANCE SUMMARY (CONT)

Task No.		Task	G Level	Configuration	Diameter - Ft	Length - Ft	Subjects	Maneuvers	Location	Comments
8		IN	0	CY	2	6	1	3	4.2	Impossible to perform maneuver
9		IN	0	CY	2.5	6	1	3	4.2	Impossible to perform maneuver, ingress only
		IN	0	CY	2.5	5	1	3	4.2	
		IN	0	CY	2.5	4	1	3	4.2	
10		IN	0	CY	3	6	1	3	4.2	Impossible to perform maneuver, ingress only
		IN	0	CY	3	5	1	3	4.2	
		IN	0	CY	3	4	1	3	4.2	
11		IN	0	CY	3.5	6	1	3	4.2	6', 5' length successful - 4' length halted after run 1 due to safety
		IN	0	CY	3.5	5	1	3	4.2	
		IN	0	CY	3.5	4	1	3	4.2	
12		IN	0	CY	5	6	1	3	4.2	
		IN	0	CY	5	5	1	3	4.2	
		IN	0	CY	5	3	1	3	4.2	
13	1	IN	1/12	CY	4	6	1	3	4.2	
	2	IM	1/12	CY	4	6	1	3	4.2	
14	1	IN	1/6	CY	4	6	1	3	4.2	
	2	IM	1/6	CY	4	6	1	3	4.2	
15	1	TI	1/12	CY	4	6	1	3	4.5	A
	2	TI	1/12	CY	4	6	1	3	4.5	B
	3	TI	1/12	CY	4	6	1	3	4.5	C
	4	TI	1/6	CY	4	6	1	3	4.5	A
	5	TI	1/6	CY	4	6	1	3	4.5	B
	6	TI	1/6	CY	4	6	1	3	4.5	C
16	1	CT	1/12	CY	4	6	1	1	4.5	SP
	2	CT	1/12	CY	4	6	1	1	4.4	CU
	3	CT	1/12	CY	4	6	1	1	4.4	CY
	4	CT	1/6	CY	4	6	1	1	4.4	SP
	5	CT	1/6	CY	4	6	1	1	4.4	CU
	6	CT	1/6	CY	4	6	1	1	4.4	CY
17	1	-	1/12	-	-	-	1	3	4.6	Walking
	2	-	1/6	-	-	-	1	3	4.6	Walking
18	1	R	1/12	CY	4	6	1	3	4.3	Test discontinued after

TABLE I - TASK PERFORMANCE SUMMARY (CONT)

Task No.		Task	G Level	Configuration	Diameter - Ft	Length - Ft	Subjects	Maneuvers	Location	Comments
										initial run due to safety restrictions
18	2	R	1/6	CY	4	6	1	3	4.3	Test discontinued after initial run due to safety restrictions
19	1	IN	0	SP	7	-	1	1	4.2	
	2	IM	0	SP	7	-	1	1	4.2	
	3	MA	0	SP	7	-	1	1	4.6	
	4	MA	0	SP	7	-	1	1	4.6	
20	1	IN	0	CP	-	-	1	1	4.2	Test not performed due to safety restriction
	2	IM	0	CP	-	-	1	1	4.2	
21		PT	0	SP/CP	-	-	1	1	4.6	

	Diameter (Inches)	Length	TASK NUMBER																				
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Cylindrical Airlock Equipment	24	72								x													
	30	72									x												
		60									x												
		48									x												
	36	72										x											
		60										x											
		48										x											
	42	72											x										
		60											x										
		48											x										
	48	72	x	x	x	x	x	x	x						x	x	x	x		x			
		54							x														
		36							x														
		18							x														
	60	72												x									
		60												x									
		36												x									
		24												x									
Transfer Packages						x												x					
Exit Bar and Tether			x	x		x	x	x	x	x				x	x			x		x	x		x
External Handhold							x																
External Handrail							x														x		
Torque Panel					x												x						
Internal Handhold			x	x		x		x							x	x		x		x			
Internal Foothold																	x						
7' Spherical Airlock																					x		x
Capsule																						x	x

Figure 4.1-1 PRIMARY AND ANCILLARY EQUIPMENT USED IN THE TASK PERFORMANCE

4.2 INGRESS-EGRESS

4.2.1 GENERAL OBJECTIVES

The tasks detailed in this section were configured to experimentally investigate the operational characteristics involved in the performance of an ingress-egress maneuver by means of water immersion simulation. The major characteristics of ingress-egress maneuvers investigated during this portion of the study are:

- Total ingress-egress feasibility with various geometry airlocks.
- The effects of airlock diameter and length variation on ingress-egress operation.
- Benefits derived from the employment of internal and external traction aids.
- The effect of gravity level variation on ingress-egress performance.

To investigate these characteristics, a 16mm black and white film record was kept from which the following quantitative measurements were taken.

- Time required for the performance of the total ingress-egress maneuver and pertinent subtasks.
- The angle of flexure at the elbow, hip and knee relative to time.

The time-task measurements were used in Phase II as the main criteria in determining the task difficulty. Because of the interdependence of performance times on such critical parameters as initial positioning, subject's variance of task performance rate, etc., it was determined that time could not be used as the unique determinant of performance and was not a reliable measure of relative difficulties. To supplement the time-motion analysis, body and limb flexure angles were measured; specifically, the elbow, hip and knee. These measurements were performed for one run of each task of a non-demonstration nature.

The use of the angle of flexure data provided information as to the amount of work that was required for the performance of each maneuver, since the flexure of the limbs is closely related to the amount of work performed by the subject. The area under the curve of the flexure angle frequency graphs is proportional to the amount of work performed and indicates the comparative degree of difficulty between tasks.

The experiment-simulations relative to ingress-egress comprised the tasks shown in Table II.

TABLE II

TASKS COMPRISING EXPERIMENTS
RELATIVE TO INGRESS-EGRESS MANEUVERS

Task No.	Title
1.	Normal Ingress-Egress at Simulated Zero Gravity Through a 48" Diameter Airlock-6' Length
2.	Modified Ingress-Egress at Simulated Zero Gravity Through a 48" Diameter Airlock-6' Length
7.	Normal Ingress-Egress at Simulated Zero Gravity Through a 48" Diameter Airlock at Various Lengths
8.	Normal Ingress-Egress at Simulated Zero Gravity Through a 24" Diameter Airlock Various Lengths
9.	Normal Ingress-Egress at Simulated Zero Gravity Through a 30" Diameter Airlock Various Lengths
10.	Normal Ingress-Egress at Simulated Zero Gravity Through a 36" Diameter Airlock Various Lengths
11.	Normal Ingress-Egress at Simulated Zero Gravity Through a 42" Diameter Airlock Various Lengths
12.	Normal Ingress-Egress at Simulated Zero Gravity Through a 60" Diameter Airlock Various Lengths
13.	Normal Ingress-Egress at Simulated 0.08 G and 0.16 G Through a 48" Diameter Airlock
14.	Modified Ingress-Egress at Simulated 0.08 and 0.16 G Through a 48" Diameter Airlock
19.	Normal Ingress-Egress Through a Spherical Airlock at Simulated Zero Gravity
20.	Normal Ingress-Egress From a Capsule Geometry Spacecraft at Simulated Zero Gravity

4.2.2 EQUIPMENT DESCRIPTION

The operational characteristics of spherical, cylindrical and capsule hatch type airlocks were investigated. These airlocks were submersed in approximately 10 feet of water and suspended approximately 18 inches above the pool floor. The airlock configurations are shown in Figures 4.2.1 - 4.2.3.

The cylindrical airlocks consisted of the following hardware:

a. Two clear plastic end panels fitted with one manually operated hatch on each panel. For the 48" diameter airlock, these doors consisted of an oval door, 28" x 36", with the major axis aligned with the vertical and opening in and a circular door, 32" diameter, opening outward. For airlock diameters other than the 48" diameter, the oval door was replaced by an inward opening, 32" diameter circular door.

b. For the 48" diameter airlock, the end panel containing the oval door was fitted with an exit bar, in the form of a 5 ft. length of 1.25 inch standard steel pipe, mounted perpendicular to the plane of the panel. The remaining panel was fitted with an 8 ft. length of 0.75 inch diameter stranded nylon rope used as a tether line.

c. The cylindrical sections of the airlocks for the diameter variation tests were constructed of a heat-formed clear plexiglass material. These cylinders were 24", 30", 36", 42", 48", 60" in diameter and 72" long. The end panels were constructed to permit the six cylindrical sections to be interchanged. The airlocks were hinged in such a manner that the upper half of the cylinder could be lifted open in the event of emergency conditions.

d. To provide variable airlock lengths, a circular plywood bulkhead was placed in the cylinders and secured with barrel bolts which dropped into pre-drilled holes at the appropriate positions.

The spherical airlock was provided by NASA-LRC and constituted the following:

a. A 7 foot hollow spherical ball made of reinforced fiberglass.

b. Two manually operated 36" diameter circular doors; one door opening in and the other outward.

c An exit bar and tether line employed in the same manner as those used on the cylindrical airlocks.

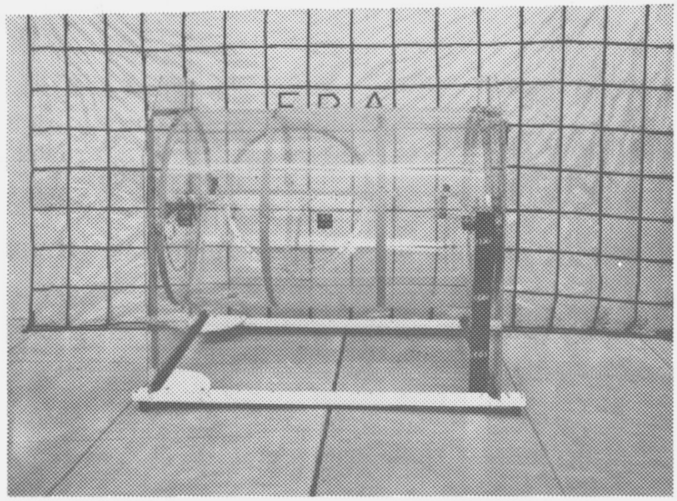
d. A tubular handrail which completely encircled the airlock.

In addition to the airlocks previously described, NASA-LRC further provided the capsule-hatch configuration shown in Figure 4.2.3 for purposes of demonstration of ingress-egress techniques. This configuration, originally used in the LRC-GEMINI docking simulation was constructed as follows:

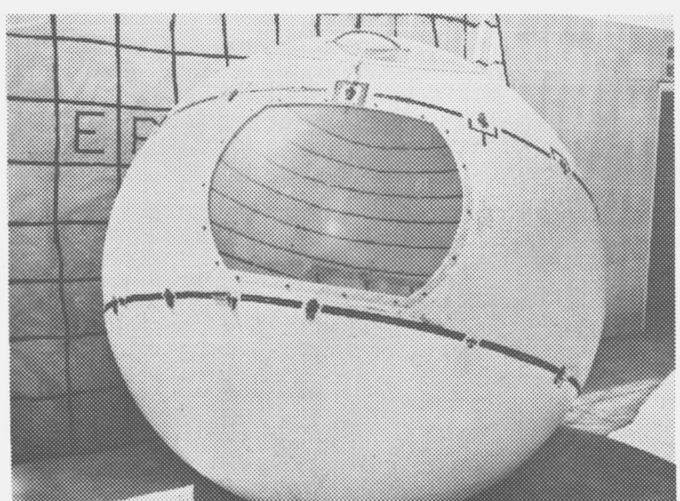
a. The basic configuration was that of a frustum of a cone with a base diameter of 81" and half-angle of 18.5 degrees, combined with a 38.5" diameter quasi-cylindrical extension section 60" in length.

b. The capsule was constructed of an aluminum tubular frame, with sheet aluminum skin.

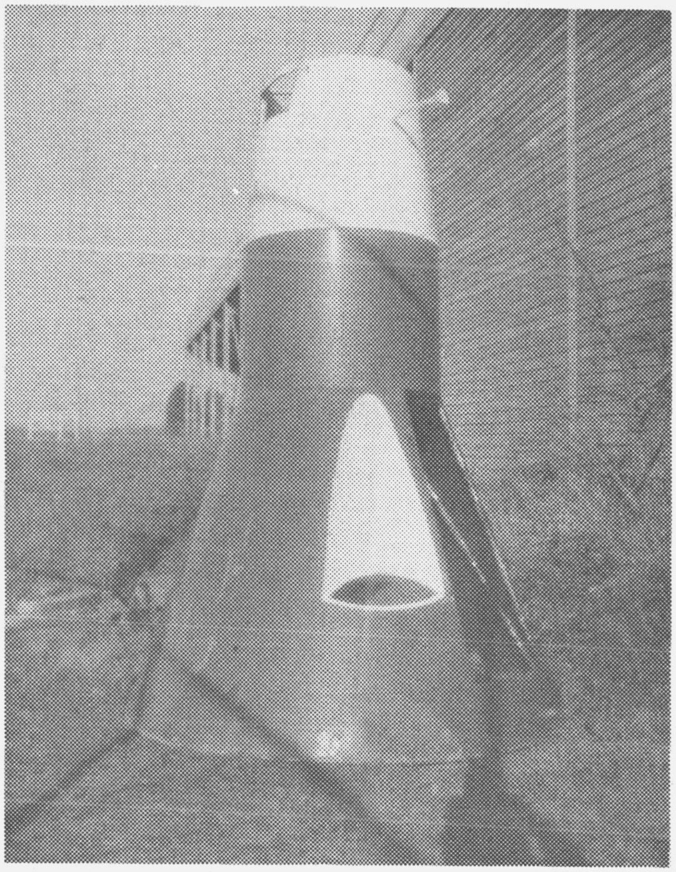
c. The capsule was equipped with a pair of manually operated hatches on the conical surface, hinged to open toward each other. The free opening of each hatch measured 51" long by an average width of 28.5". In later experiments the doors were altered to open in the opposite direction to make them compatible with the actual Gemini configuration.



4.2-1 48" Diameter, 72" Long Cylindrical Airlock Configuration



4.2-2 7' Diameter Spherical Airlock Configuration



4.2-3 Capsule Hatch Type Configuration

4.2.3 NORMAL INGRESS-EGRESS AT SIMULATED ZERO-GRAVITY THROUGH A 48" DIAMETER AIRLOCK, 6' LENGTH - TASK 1

4.2.3.1 OBJECTIVES

The subject, wearing an Arrowhead, Mark IV-FPS pressurized to 3.5 PSI above ambient performed a normal ingress-egress maneuver through the 48" diameter, 6' long airlock previously described. The normal ingress-egress mode consisted of the tasks shown in Table III with the subject performing in a head-first frontal manner. Two separate subjects were required to perform the maneuver in the direction c/o-circular to oblong hatch, and o/c-oblong to circular hatch, three successive times.

4.2.3.2 PERFORMANCE ANALYSIS

4.2.3.2.1 o/c DIRECTION-RUN 1

Elapsed Time: 0.0 Seconds

The maneuver began with the subject grasphing the exit bar with his left hand, approaching the oval door and reaching for the door latch handle with his right hand. The sequence of events is shown in Figure 4.2.4-4.2.5. After rotating the latch handle 90°, he pushed the door open. When the door was fully opened, the subject grasped the door frame with his left hand to position himself for entry. Using both hands to push against the inner surface of the airlock, he completed his entry.

Elapsed Time: 23.7 Seconds

Both subjects executed the entry maneuver, facing the oval door as they entered. This was adjudged a direct result of door configuration and precautionary measures taken by the subject.

By entering, facing the oval door, the subject was able to align his body parallel to the major axis of the oval hatchway. Since the major axis of the hatchway is 36" compared to the minor axis of 28", the subject found entry easier in this configuration.

The main reason the subjects entered facing the door was to prevent entanglement of their air hoses in the latch mechanism. Until this practice was initiated, the subjects often fouled their lines in the latch mechanism.

By pushing on the frame of the oval door with the left foot and then with the right foot, the subject reduced his overall length so that the turnaround maneuver could be accomplished. Turning approximately 90° to his right, the subject initiated door closure, and simultaneously completed the door closure and turnaround. The door was latched by a 90° rotation of the latch handle.

TABLE III

INGRESS-EGRESS SUBTASK DESCRIPTION

Subtasks	Description
A	Approach hatch (1), unlatch hatch (1), open hatch (1)
B	Ingress hatch (1), approach hatch (2)
C	Turnaround, approach-hatch (1)
D	Close hatch (1), lock hatch (1)
E	Execute turnaround, approach hatch (2)
F	Unlatch hatch (2), open hatch (2)
G	Egress Hatch (2)
H	Turnaround-external
I	Close hatch (2), lock hatch (2)

Elapsed Time: 33. 7 Seconds

The subject performed the second turnaround turning to his right pushing with his left hand on the door latch handle and pulling with his right hand on the handhold inside the airlock. By pushing against the airlock bulkhead with his left foot during the turnaround, he propelled himself towards the circular door upon completion of the turnaround. The subject then unlatched the circular door by rotating the latch handle 90° with his right hand and pushed the door open.

Elapsed Time: 52. 5 Seconds

Egress was initiated when the subject grasped the bottom edge of the door opening with both hands. Exiting the airlock, the subject grasped the latch handle with his left hand, while coming to a vertical position, and began turning to the right. Releasing the latch handle, he grasped the top edge of the door frame and continued the turnaround until he was facing the door. Grasping the tether line in his right hand, the subject closed and latched the door with his left hand.

Elapsed Time: 66.6 Seconds-Finish of Maneuver

4.2.3.2.2 c/o DIRECTION-RUN 1

The return passage began with the subject holding the tether line and unlatching and opening the door.

Elapsed Time: 0.0 Seconds

He performed the entry maneuver by pulling on the tether with his right hand and pushing against the latch handle with his left hand. As he entered, he pushed against the inside of the door frame with both hands to complete the entry.

Elapsed Time: 21.9 Seconds

The subject performed a turnaround using both his hands and feet against the airlock walls to supply needed traction. Holding onto the door frame with his left hand, he pulled the door closed.

Elapsed Time: 42.9 Seconds

The subject again turned to his left to face the oval door. He then unlatched and pulled open the oval door.

Elapsed Time: 60.7 Seconds

Using the latch handle as a means of propulsion, he exited the airlock. During his exit the subject grasped the exit bar with his right hand. Once free of the airlock, he grasped the bar with both hands to execute a turnaround. Now facing the oval hatchway and holding the exit bar with his left hand, the subject pulled the door closed.

Elapsed Time: 86.3 Seconds-Finish of Maneuver

4.2.3.3 RESULTS

The subtask performance time for the normal ingress-egress maneuver at simulated zero-gravity are shown for Subjects A and B in Figures 4.2.6-4.2.9 for the c/o and o/c directions. The performance times are shown compared to similar performance at one-gravity. Table IV shows the results of Task I performance as regards the total maneuver times. It is evident from the comparison of Table IV that the effect of zero-gravity is to increase the maneuver times over similar performance at ground-1G conditions.

Also shown in the Figures 4.2.6-4.2.9, is the effect of motion aids on the performance of normal ingress-egress with simulated zero gravity conditions. The data indicates that although motion aids enabled the subject to control his pre-position attitude, e.g. his attitude while free of support from the airlock, they did not significantly decrease his overall performance times. The motion aids did decrease the subtask times for subtasks external to the airlock structure, which are not strictly primary ingress-egress sub-functions.

Three pertinent measures of performance were chosen to indicate the degree of difficulty of the individual task variations since no direct metabolic measurements were made. These were the elbow, hip and knee angle frequency profiles. Observation of ingress-egress performance of pressure-suited subjects in simulated weightless conditions provided by water immersion techniques with suit pressure as a variable, which was performed on Phase II indicated that all significant suit motions were evidenced in these angle measurements. This correlated to subjective comments as to task difficulty. Figures 4.2.10-4.2.12 show the frequency and cumulative frequency of these angle measurements for a single run of Subject A. The time increment chosen for analysis was one second and angles were adjudged by visual film analysis and are accurate to approximately $\pm 5^{\circ}$.

TABLE IV

TOTAL PERFORMANCE TIME° -TASK 1
NORMAL INGRESS-EGRESS AT
SIMULATED ZERO GRAVITY-TASK 1

	Total Performance Time - Seconds			
Direction	Subject A	Subject B	Average	1 "G" Baseline
c/o	80.0	103.3	91.7	55.2
o/c	84.6	83.5	84.2	56.7
Combined	164.6	186.8	175.7	111.9

°Average of three consecutive maneuvers, without motion aids

Open Door

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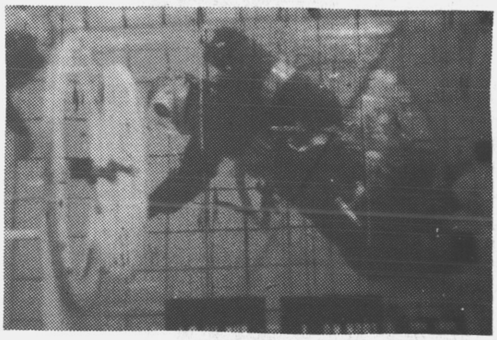
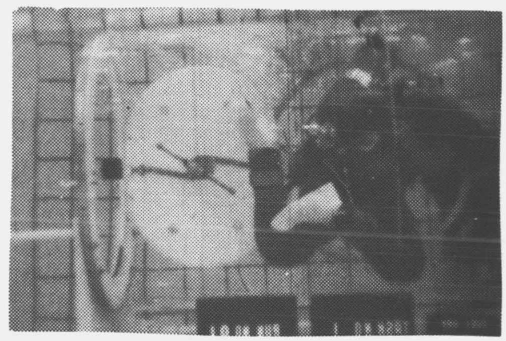


Turnaround



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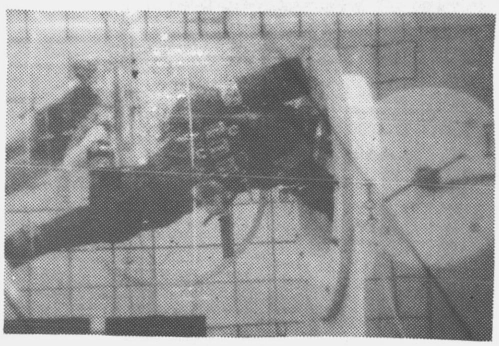

Turnaround

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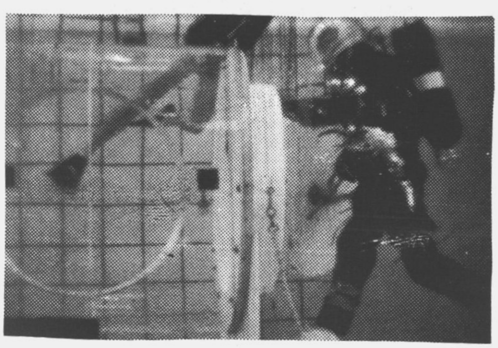

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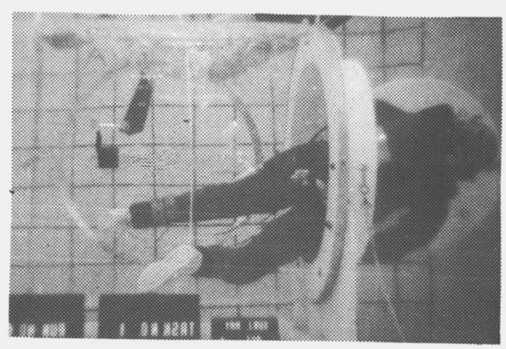
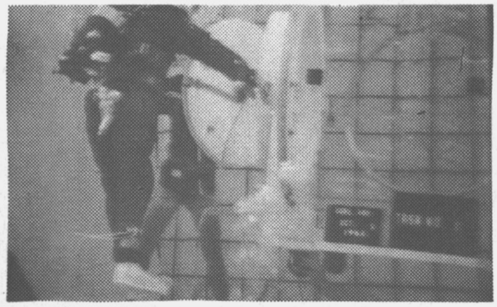
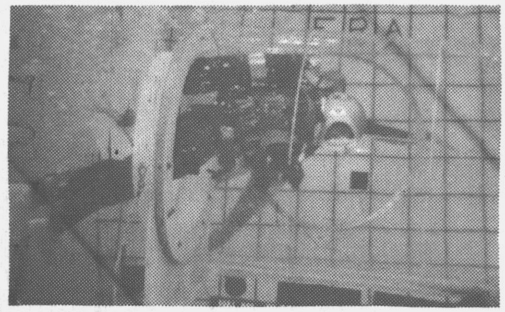


Close Door

4.2-4 Normal Ingress-Egress Sequence, O/C Direction - Task 1



Open Door



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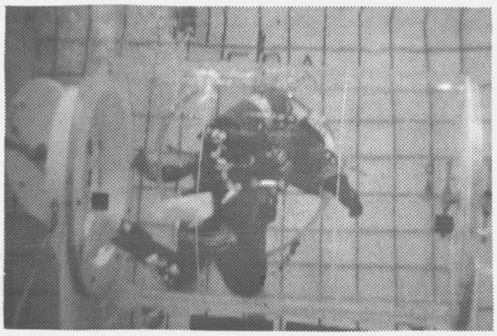
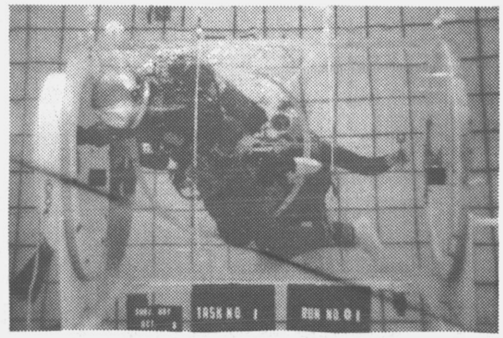
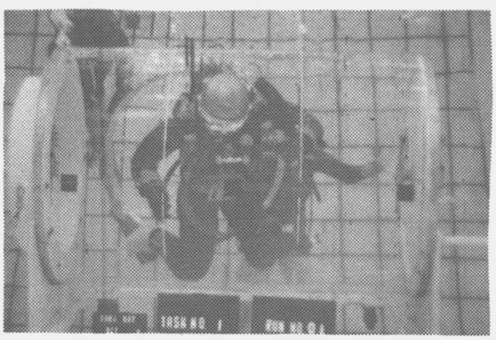


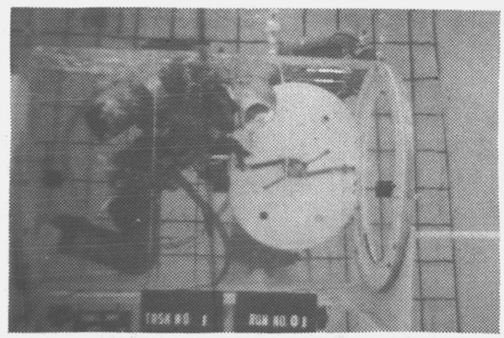
Turnaround



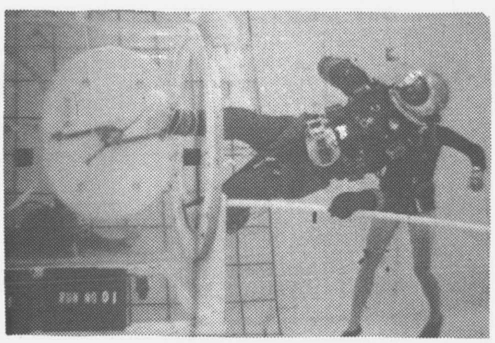
Close Door



Turnaround



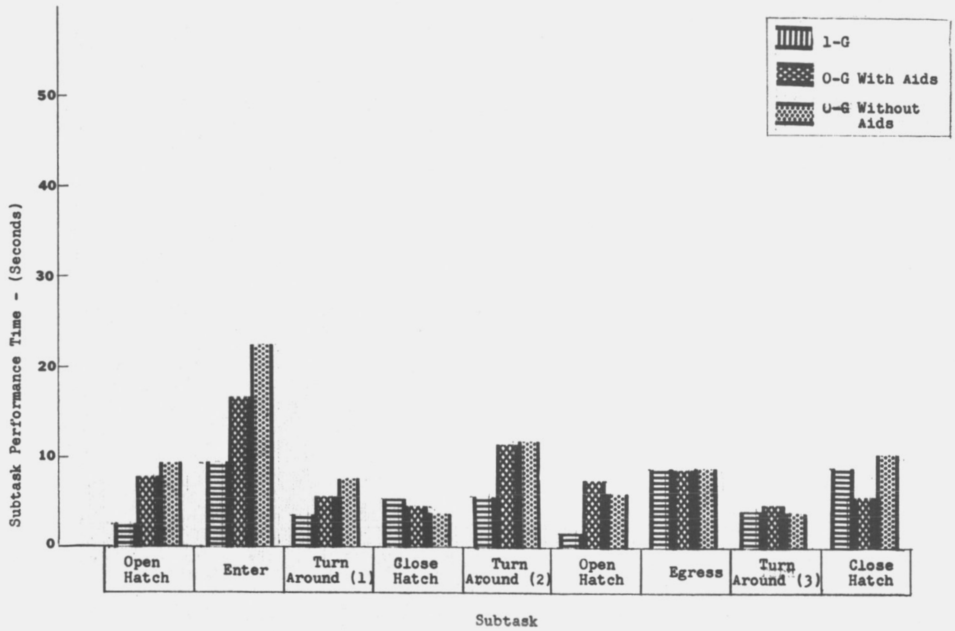
Open Door



Exit

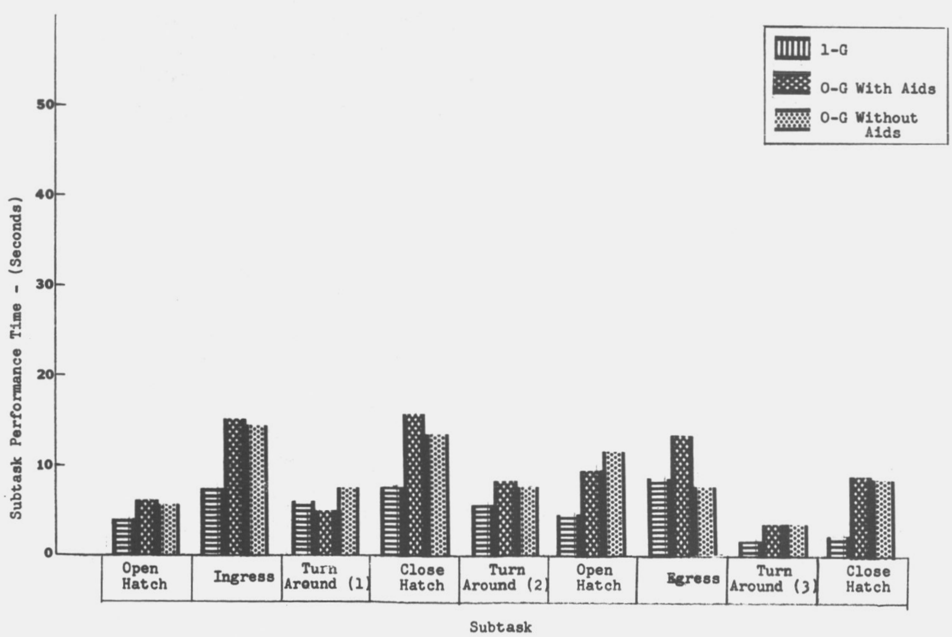
Close Door

4.2-5 Normal Ingress-Egress Sequence-C/O Direction - Task 1



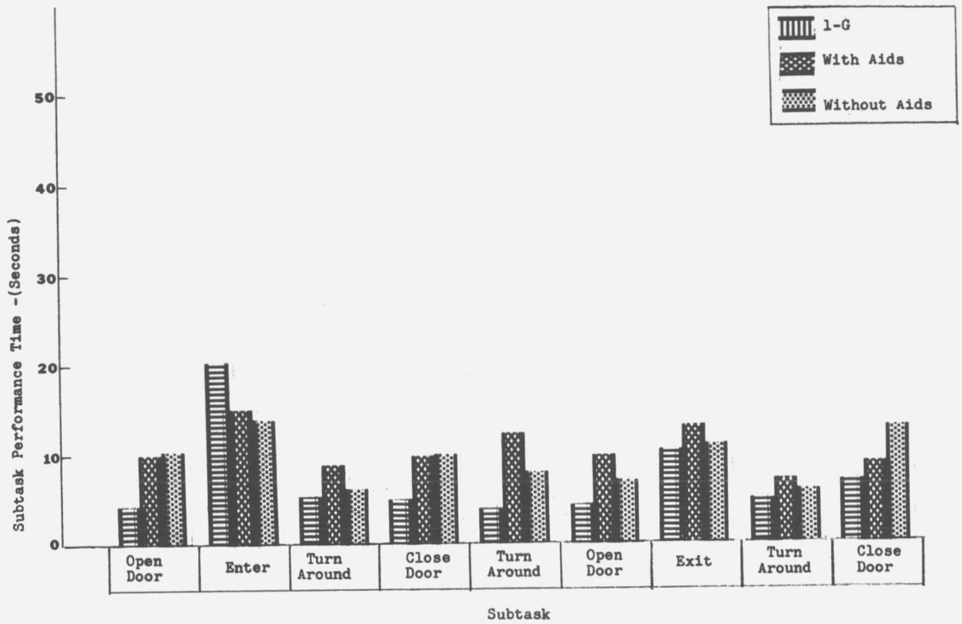
The Effect of Motion Aids on Subtask Performance Times Subject A Direction O-C

Figure 4.2-6



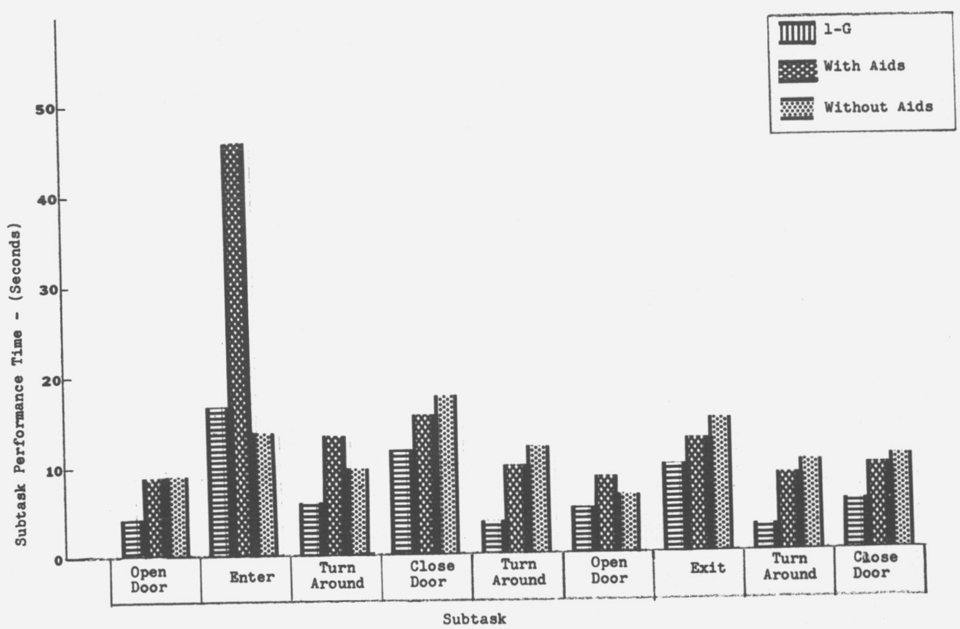
The Effect of Motion Aids on Subtask Performance Time Subject A Direction C-O

Figure 4.2-7



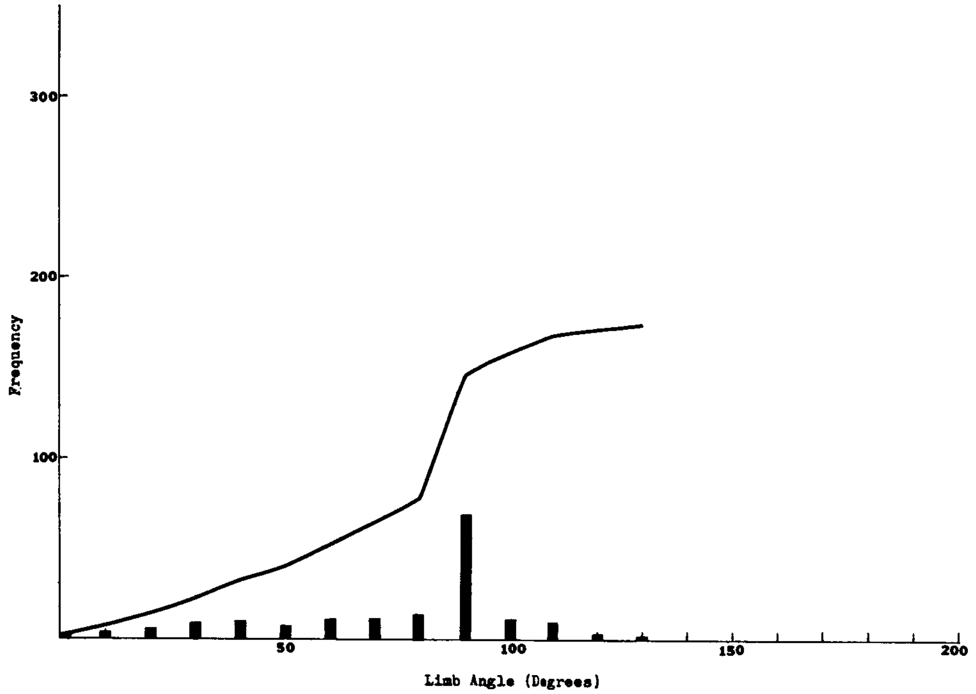
The Effect of Motion Aids on Subtask Performance Time Subject B Direction O-C

Figure 4.2-8



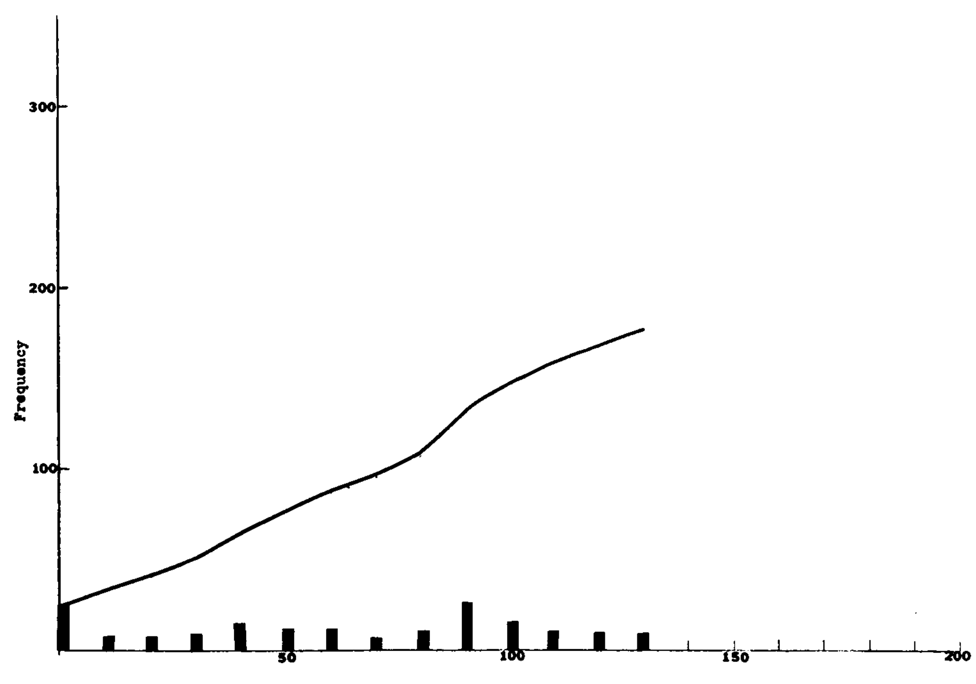
The Effect of Motion Aids on Subtask Performance Time Subject B Direction C-O

Figure 4.2-9



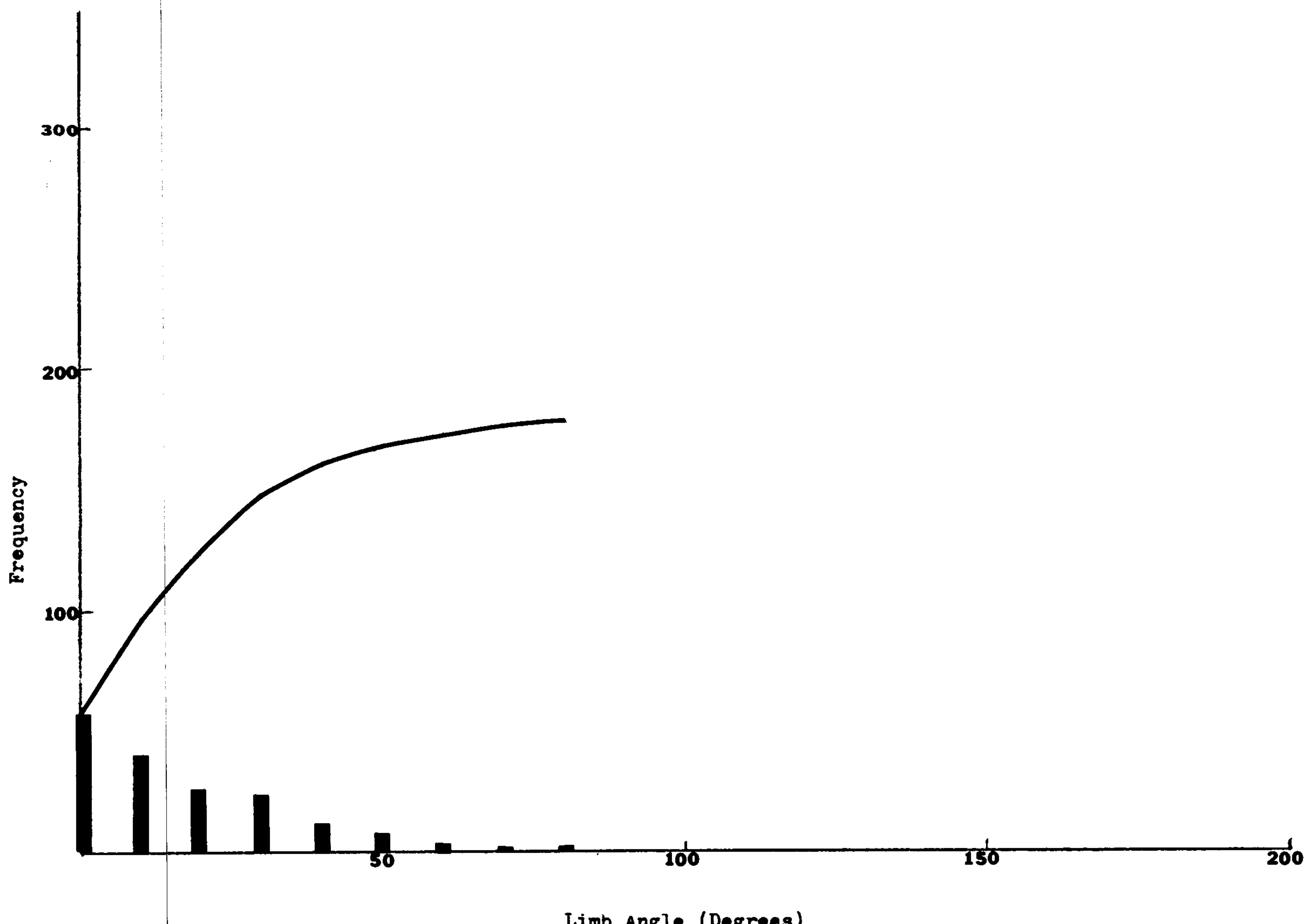
Limb Angle Frequency Profile - Elbow Angle - Subject A - Task 1/Run 1

Figure 4.2-10



Limb Angle Frequency Profile - Knee Angle - Subject A - Task 1/Run 1

Figure 4.2-11



Limb Angle Frequency Profile - Hip Angle - Subject A - Task 1/Run 1

Figure 4.2-12

4.2.4 MODIFIED INGRESS-EGRESS AT SIMULATED ZERO-GRAVITY THROUGH A 48" DIAMETER AIRLOCK, 6' LENGTH-TASK 2

4.2.4.1 OBJECTIVES

A pressurized-suited subject, wearing an Arrowhead, Mark IV-FPS pressurized to 3.5 PSI above ambient performed a modified ingress-egress maneuver through the 48" diameter, 6' long airlock previously described. The modified ingress-egress maneuver consisted of the tasks shown in Table III with the subject performing steps B and C in a feet first manner. Two separate subjects were required to perform the maneuver in the direction c/o, circular to oblong door and o/c, oblong to circular door three successive times.

4.2.4.2. PERFORMANCE ANALYSIS

4.2.4.2.1 o/c DIRECTION-RUN 1

Elapsed Time: 0.0 Seconds

This maneuver comprises a feet-first entry and feet-first exit. The sequence of events is shown in Figure 4.2.13-4.2.14. The maneuver began with the subject grasping the exit bar with his left hand. Approaching the oval door, he reached for the door latch handle with his right hand. Rotating the handle 90°, he pushed the door open.

By grasping the exit bar with his left hand and the upper edge of the door frame with his right hand, the subject was able to swing his legs up until his feet entered the hatchway. By maintaining his hold on the door frame he was able to guide himself into the airlock.

Elapsed Time: 23.9 Seconds

The entry completed, he pushed the door closed. In a manner similar to Task 1, the subject executed a turnaround. Now facing the circular door, the subject unlatched and pushed the door open. After executing another turnaround, the exit maneuver began.

Elapsed Time: 54.8 Seconds

The subject performed the feet-first egress by pushing himself out of the airlock until he was able to reach the tether line. Using the tether to aid in positioning himself, he closed and latched the door.

Elapsed Time: 90.0 Seconds-End of Maneuver

Difficulty was experienced during the exit maneuver. The subject was hampered by an inability to maintain traction during the exit. This loss of traction greatly reduced the velocity at which he could exit. This was caused by three interrelated factors:

(a) neutral buoyancy
(b) the smooth walls of the airlock
(c) the lack of motion aids within the airlock to aid in exit

This difficulty was not experienced during entry because the subject was able to use the positioning capability of his hands while holding onto the door frame.

4.2.4.2.2 c/o DIRECTION-RUN 1

Elapsed Time: 0.0 Seconds

The return passage began with the subject holding the tether line in his right hand and his body perpendicular to the airlock axis. Rotating the latch handle 90°, he pulled the door open. Holding the upper edge of the door frame with his left hand and pulling on the tether with his right hand, the subject was able to place his feet through the hatchway and enter the airlock.

Elapsed Time: 26.3 Seconds

His entry complete, he closed the circular door and executed a turnaround to face the oval door. Unlatching the door and pulling it open, the subject turned around to position himself for the exit.

Elapsed Time: 58.9 Seconds

The egress maneuver was accomplished by using the door latch handle as a means to propel the subject far enough to secure the exit bar. Grasping the bar, the subject pulled the door closed and latched it. During this egress maneuver, the latch handle of the inward opening door supplied the subject the motion aid he lacked while exiting the circular door.

Elapsed Time: 100.6 Seconds-Finish of Maneuver

4.2.4.3 RESULTS

The combined effects of maneuver direction and hatch configuration are shown in Figure 4.2-15-4.2-16. In the simulated zero gravity condition, ingress generally took less time than egress. This was accounted for in the following manner: the greatest hindrance to the performance of this maneuver was the reduction of visual capability and kinesthesis. Suit limitations prevent any large movement in the head and neck area. Consequently, in order to align himself for entry and exit, the subject had to observe his feet. This was best accomplished by bending the body at the midsection. This was most easily done during ingress when the subject was not restricted by the airlock envelope.

Another important factor affecting ingress-egress was the subject's ability to use his hands. It was observed during the tests and film analysis that the subject was able to make better use of the positioning power of his hands during ingress than during egress.

In conjunction with this, the data shows that ingress through the oval door took less time than ingress through the circular door. This was accounted for by observing the limitation of movement experienced by a subject wearing an FPS. One of the most difficult positions to assume is the hands held high above the head. While entering the circular door, the subject used the door handle as a motion aid to propel and guide himself into the airlock. In order to accomplish this, he had to assume the "hands up" position which greatly decreased the efficiency of the entry. Use of the latch handle of the oval door, however, permitted the hands to be kept below shoulder height at all times. This enabled the subject to guide himself more easily through the hatchway. This indicates that handholds should be placed internal to the airlock near the end panels to provide assistance during entry.

Figure 4.2-17-4.2-19 show the frequency distribution of the degree of bending at the subject's hip, knee and elbow for one run of Task 2. Comparing the frequency of distributions of Task 1 and Task 2, the greater degree of bending experienced in the feet-first entry and exit, it would appear that Task 2 would require more effort than Task 1. This is verified from the time-motion study which shows an increase of 20% over Task 1.

The task performance charts indicate that an optimum maneuver might be accomplished by performing a feet-first entry and head-first exit, thus two turnaround per run could be eliminated. This maneuver would permit maximum use of the subject's hands in controlling body movement. To support this conclusion, the time averages of Task 1 and Task 2 were combined to form this composite maneuver. This result is shown in Table V. This data suggests a decrease of 18% and 34% in performance time compared with the normal and modified ingress-egress maneuver respectively.

TABLE V

SUBTASK AND TOTAL PERFORMANCE TIMES FOR THE "COMPOSITE" INGRESS-EGRESS MANEUVER-COMBINED TIME 145.4 SECONDS[o]

Subtask	Description	Performance Times-Seconds	
		o/c	c/o
A	Approach hatch (1), unlatch hatch (1), open hatch (1)	7.5	9.0
B	Ingress hatch (1)	16.4	27.3
C	Close hatch (1), latch hatch (1)	13.7	8.4
D	Turnaround, approach hatch (2)	10.5	8.4
E	Unlatch hatch (2) open hatch (2)	8.5	13.4
F	Egress hatch (2)	4.8	3.4
G	Turnaround-external close hatch (2) latch hatch (2)	5.4	8.7
Total		66.8	78.6

[o]Average of three consecutive runs, without motion aids.

Open Door

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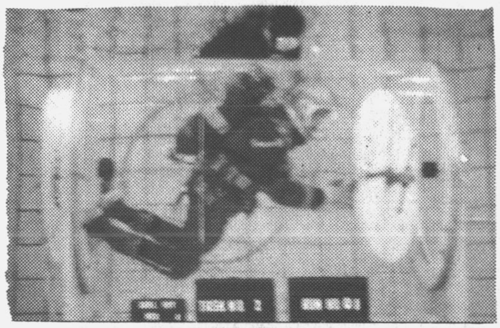
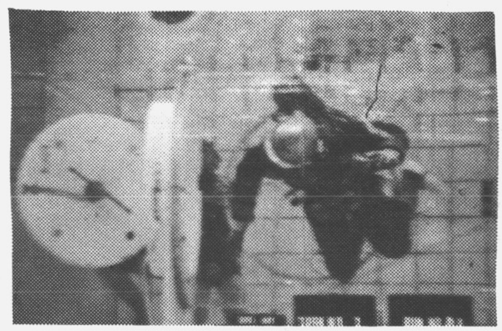


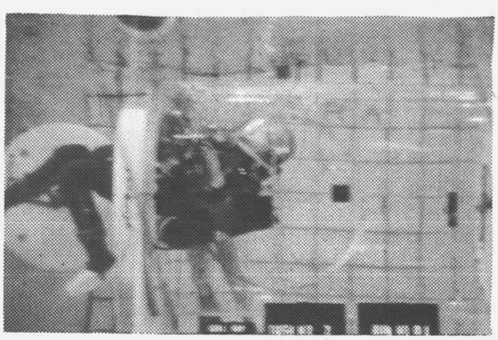
Close Door

Turnaround

Open Door



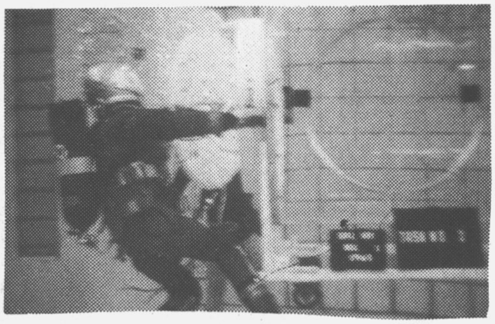
Turnaround



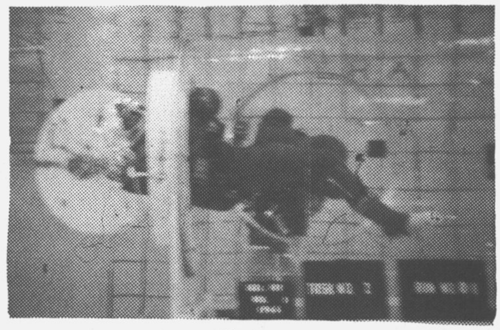
Exit

Close Door

4.2-13 Modified Ingress-Egress Sequence, O/C Direction - Task 2



Open Door



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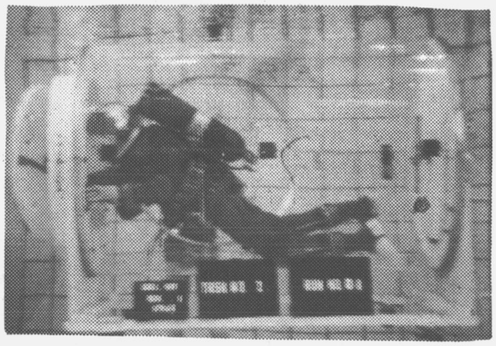

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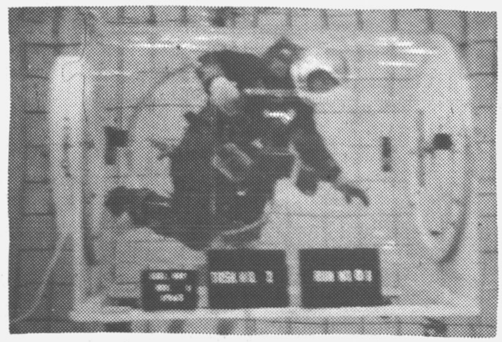
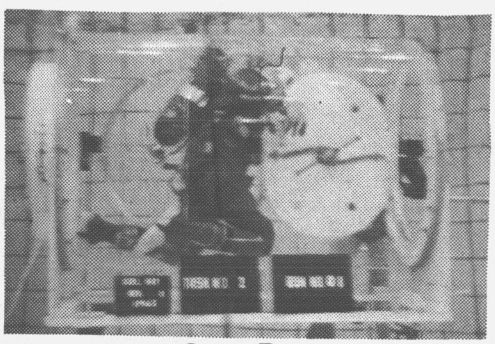


Turnaround



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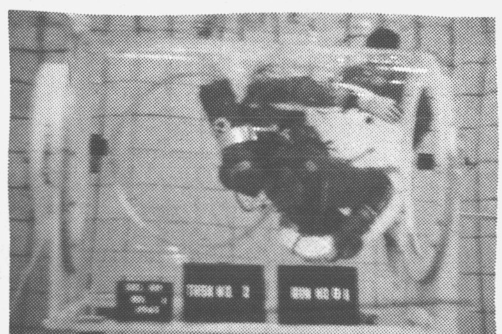
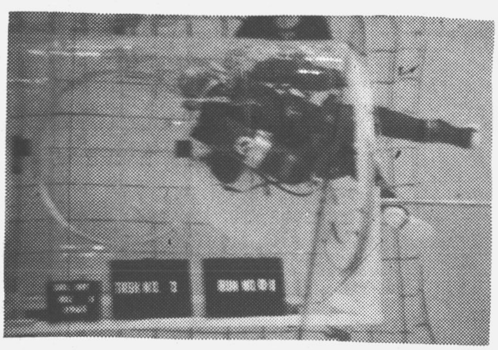


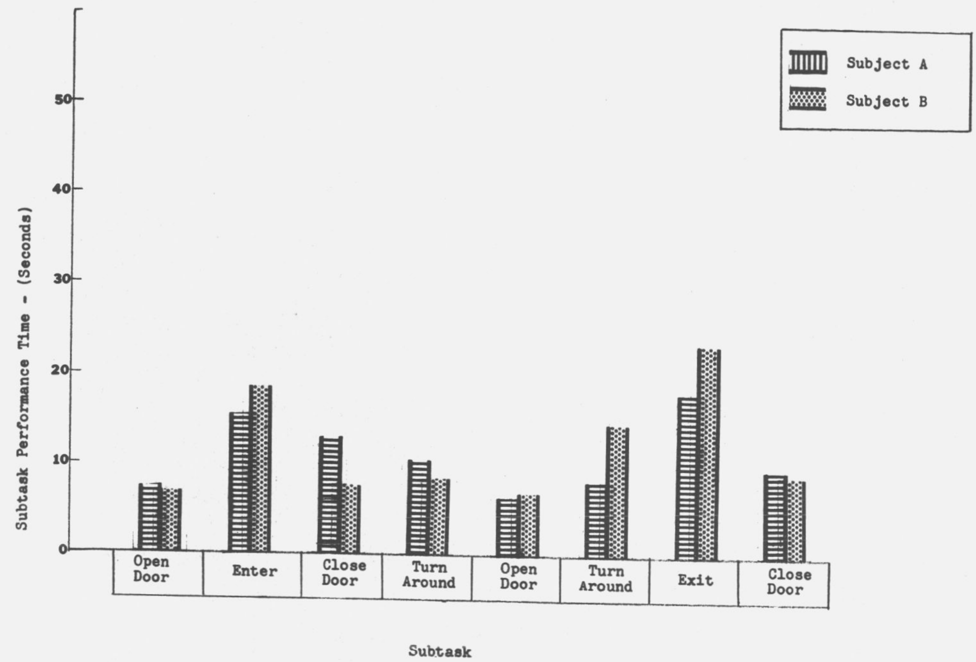
Turnaround



Exit

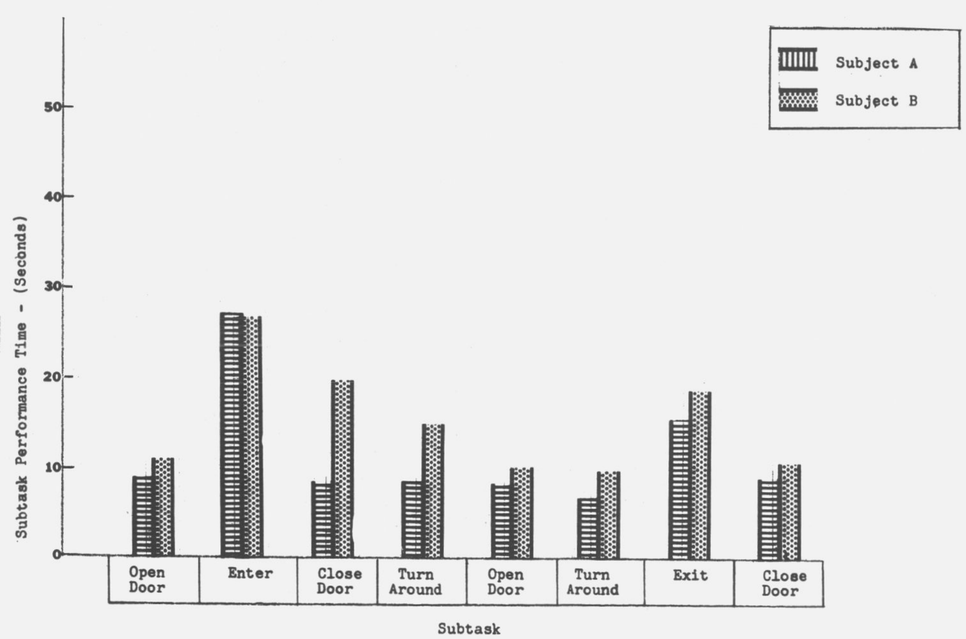
Close Door

4.2-14 Modified Ingress-Egress Sequence, C/O Direction - Task 2



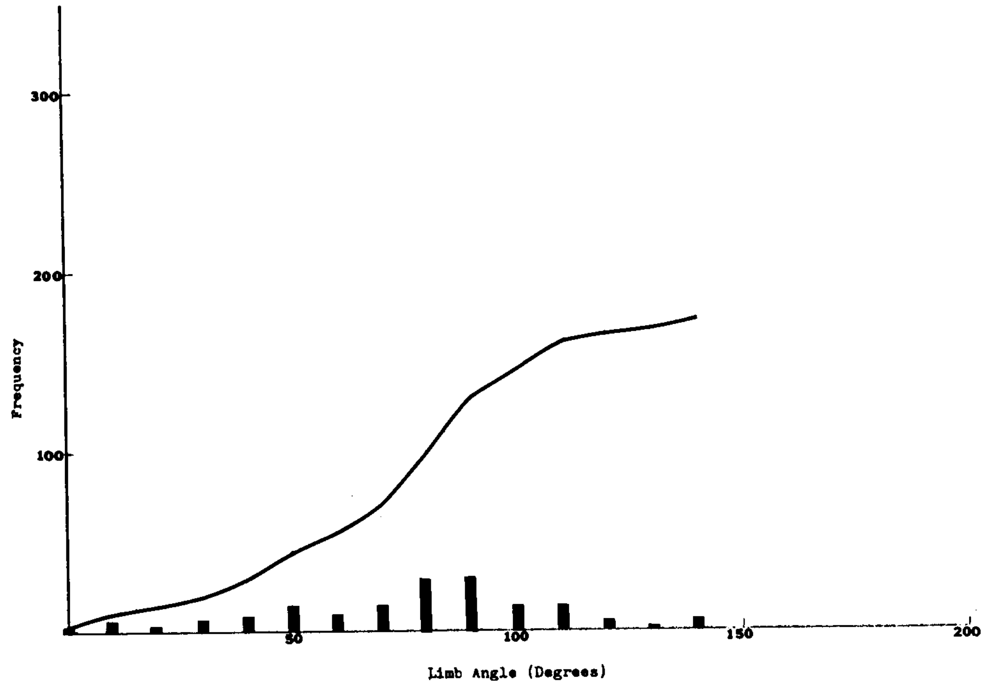
Subject Comparison of Subtask Performance Time Subjects A and B, With Aids, O-G Direction O-C

Figure 4.2-15



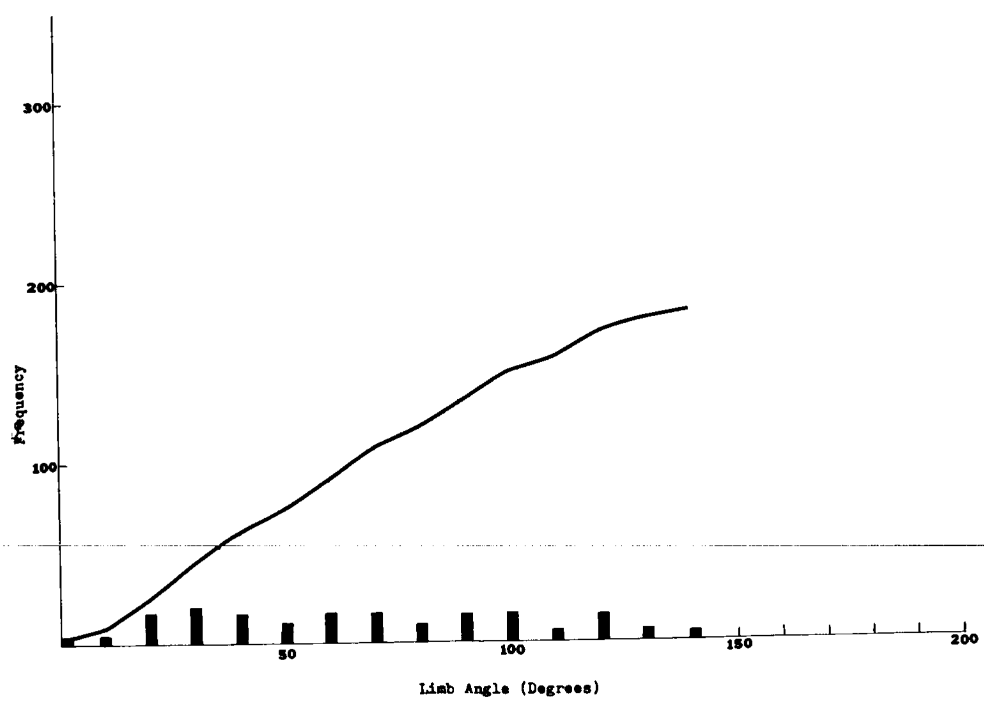
Subject Comparison of Task Performance Time Subjects A and B, With Aids, O-G Direction C-O

Figure 4.2-16



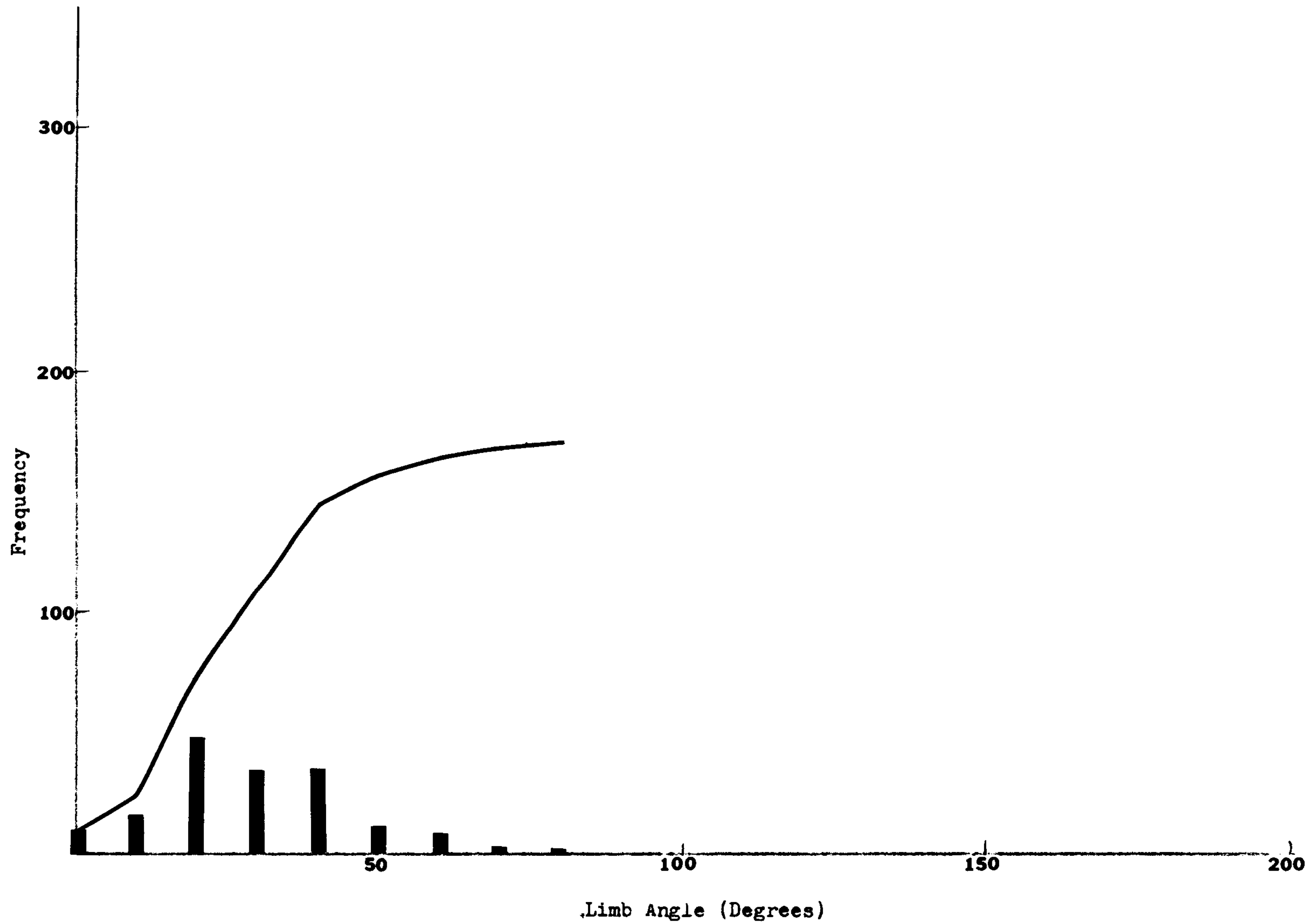
Limb Angle Frequency Profile - Elbow Angle - Subject A - Task 2/Run 1

Figure 4.2-17



Limb Angle Frequency Profile - Knee Angle - Subject A - Task 2/Run 1

Figure 4.2-18



Limb Angle Frequency Profile - Hip Angle - Subject A - Task 2/Run 1

Figure 4.2-19

4.2.5 NORMAL INGRESS-EGRESS AT SIMULATED ZERO GRAVITY THROUGH A 48" DIAMETER AIRLOCK WITH VARIABLE LENGTH-TASK 7

4.2.5.1 OBJECTIVES

This experimental task was established to determine the effect of airlock length variation on performance times and operational characteristics of normal ingress-egress maneuvers. Three airlock length variations were chosen for the 48" diameter airlock: 18", 36", 54" reflecting 1/4, 1/2, and 3/4's of the original 6' length investigated in Phase II. Maneuvers were performed for both the inward and outward opening doors. The subtask schedule was the same as that for Tasks 1, 2 except that the second turnaround within the airlock was not accomplished and egress was through the same hatch as ingress. The reduced lengths were provided by inserting a fixed bulkhead at the proper location internal to the airlock.

4.2.5.2 PERFORMANCE ANALYSIS

4.2.5.2.1 18" AIRLOCK LENGTH-RUN 1

The procedure followed for this task closely resembles the procedures followed for the maneuver in the 72" long airlock.

The task began with the subject grasping the exit bar with his left hand and unlatching the door with his right hand. Because of the airlock length, the inward opening oval door would only open 35°. The subject pushed the door open. Grasping the latch handle and door frame, he attempted to enter the airlock. He was unsuccessful, succeeding only in getting his head, right arm and shoulder within the airlock. The results of this attempt is shown in Figure 4.2-20.

4.2.5.2.2 54" AIRLOCK LENGTH-RUN 2

Elapsed Time: 0.0 Seconds

The subject unlatched and opened the circular door with his left hand while grasping the tether line with his right hand. As the door opened, he made his entrance using the tether and door latch handle as motion aids during entry. The sequence of events is shown in Figure 4.2-21.

Elapsed Time: 20.0 Seconds

Once inside the airlock, the subject performed his turnaround in a manner similar to that used in the full length airlock. In the 54" airlock, the turnaround was much easier when the circular door was used than when the oval door was used. This was found to be true in all lengths used. In this length airlock, 38.5% less time was consumed for the turnaround when the circular door was used compared to the use of the oval door.

Elapsed Time: 26.5 Seconds

Completing his turnaround, the subject closed and latched the door. Hesitating a few seconds, he unlatched the door, opened it and made his exit. Once clear of the airlock, he executed a turnaround and closed the door.

Elapsed Time: 97.4 Seconds

During each of the three runs performed with a length of 54" the length of the airlock did not appear to affect the subject's performance when the circular door was used. However, the reverse was true for the use of the oval door, the maneuvers within the airlock taking a greater length of time.

4.2.5.2.3 36" AIRLOCK LENGTH

While grasping the exit bar with his left hand, the subject unlatched and opened the door. Using the door frame, latch handle and the door as motion aids, he was able to execute an entry and partial turnaround. Further movement was prohibited by the inward opening door. Unable to complete the turnaround and door closure, the subject exited the airlock and closed the door. The pertinent subtasks are shown in Figure 4.2-22.

As in the other airlock lengths, the subject was greatly hampered by the oval door and unsuccessful in his attempt to complete the maneuver. However, this was not the case for entrance through the circular door. Although difficult to perform at this length (in one case, it took 36.2 seconds to complete the turnaround), the subject was able to complete the entire maneuver. The average lapsed time being 87.8 seconds.

4.2.5.3 RESULTS

The results are shown in Figure 4.2-23-4.2-24. These figures show the times required for the performance of the designated subtasks. No times have been included for the 18 inch long airlock since the subject was unable to perform the ingress maneuver. A summary of these results are shown in Table VI.

Table VI indicates that the time required for turnaround is nearly independent of the length. This is caused by the evolution of the turnaround maneuver as the length was decreased from 54" to 36". At the 54" length, the subjects completed the ingress maneuver before starting to turnaround as was the case in the longer airlocks. However, this was not the case for the 36" length airlock. The subject did not complete ingress before the turnaround but began turning to face the hatchway while the lower extremities of his body were still on the outside of the airlock. This effectively combined ingress and turnaround into one maneuver, keeping the turnaround time nearly constant and reducing the total maneuver time as the length decreased.

TABLE VI

THE EFFECT OF AIRLOCK LENGTH VARIATION TURNAROUND AND TOTAL TIME FOR THE 48" DIAMETER AIRLOCK-ZERO GRAVITY SIMULATION

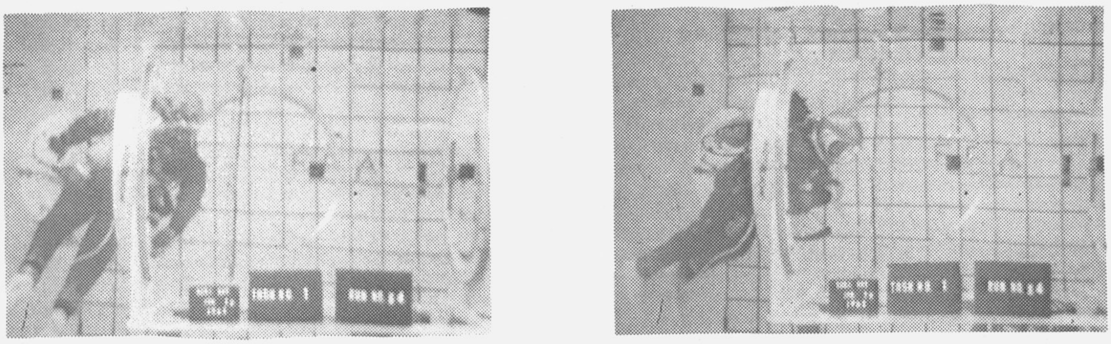
Airlock Length	Turnaround Time-Seconds	Total Maneuver Time-Seconds
	Subject A	
18"	X	X
36"	6.3	85.3
54"	5.7	85.4
	Subject B	
18"	X	X
36"	7.4	75.7
54"	9.4	92.6

°Average of 3 consecutive maneuvers, without aids

X-denotes maneuver unsuccessful

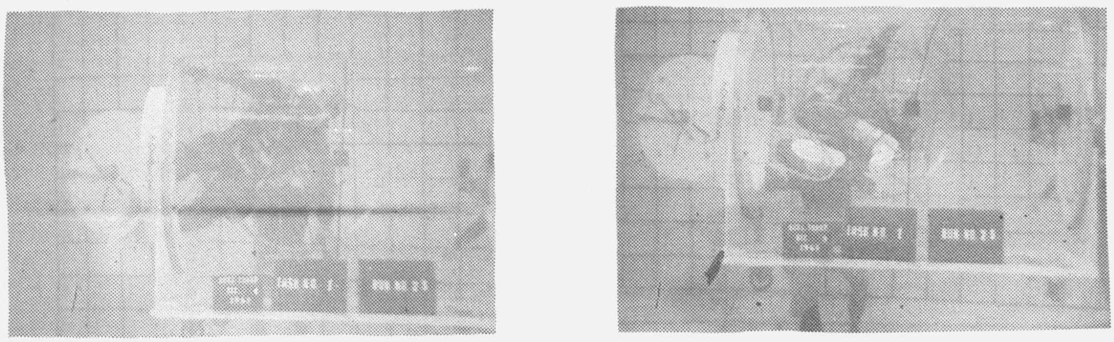
This variation of technique also had an effect on the relative amount of work performed. Figures 4.2-25-4.2-27 show the angle frequency profiles for ingress-egress through the circular door. It can be seen that length reduction of the airlock had little effect on the work performed at the elbow and hip. However, the 54" long airlock required a larger relative expenditure of energy at the knee than 36" long airlock.

Since the movement at the elbow and hip are essentially the same for the two lengths, it should be expected that the energy expenditure remains the same. However, because the technique of ingress and turnaround has changed for the 36" long airlock the energy expenditure should change. This was the case. The largest deflections at the knee occur during the turnaround maneuver. In the 36" length airlock, the turnaround was approximately 50% complete before the subject brought his legs inside the airlock, thus decreasing the time at which the knee was held at a large deflection and consequently producing a smaller energy expenditure at the shorter length.



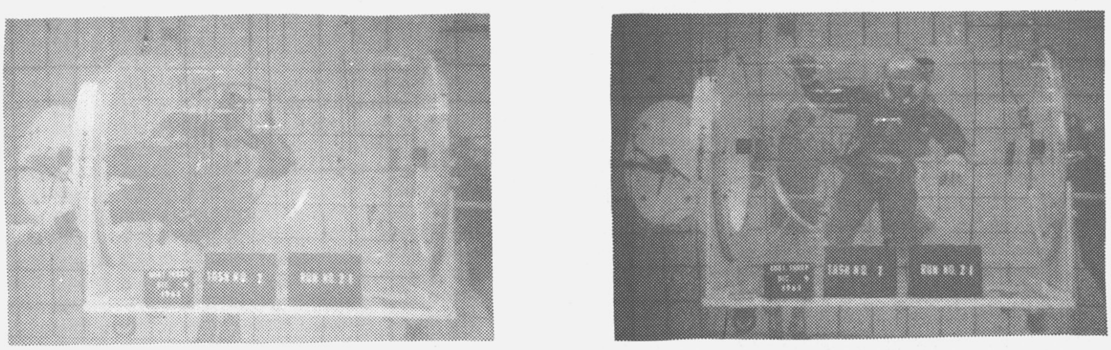
Attempt to Enter

4.2-20 Sequence Of An Ingress-Egress Maneuver In An 18" Long Airlock



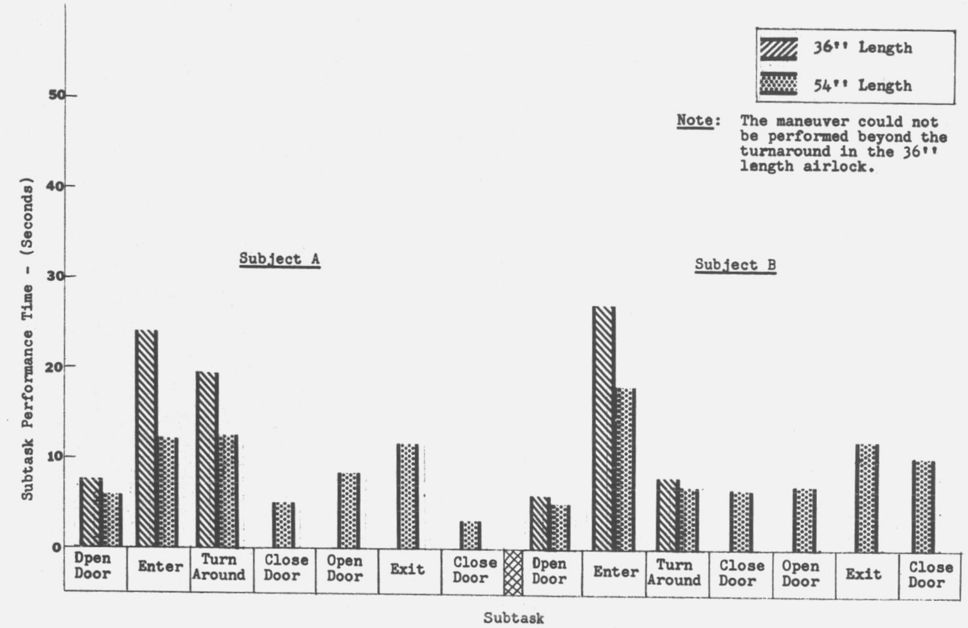
Enter | Turnaround

4.2-21 Sequence Of An Ingress-Egress Maneuver In A 36" Long Airlock



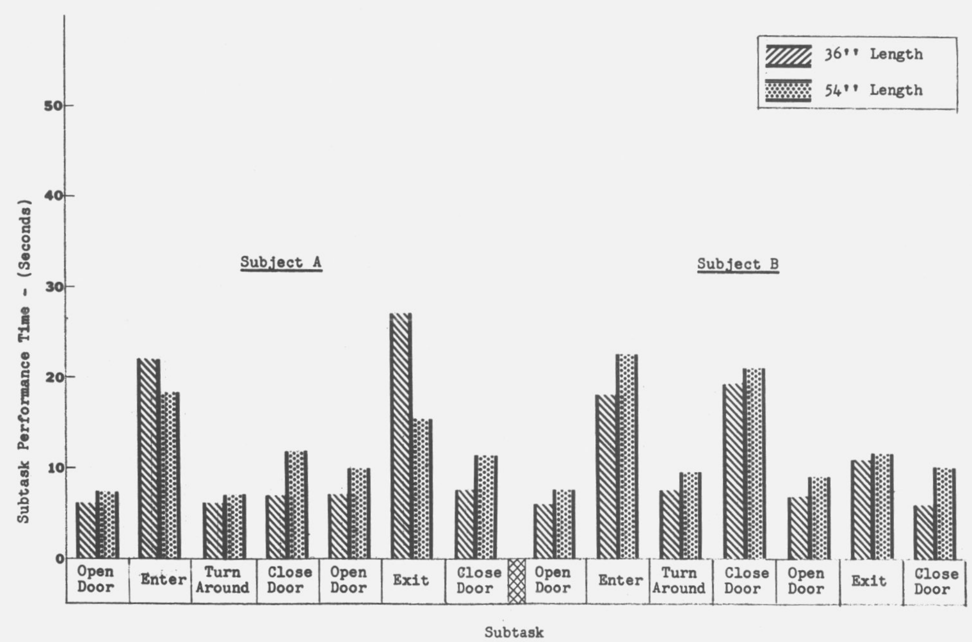
Enter | Turnaround

4.2-22 Sequence Of An Ingress-Egress Maneuver In A 54" Long Airlock



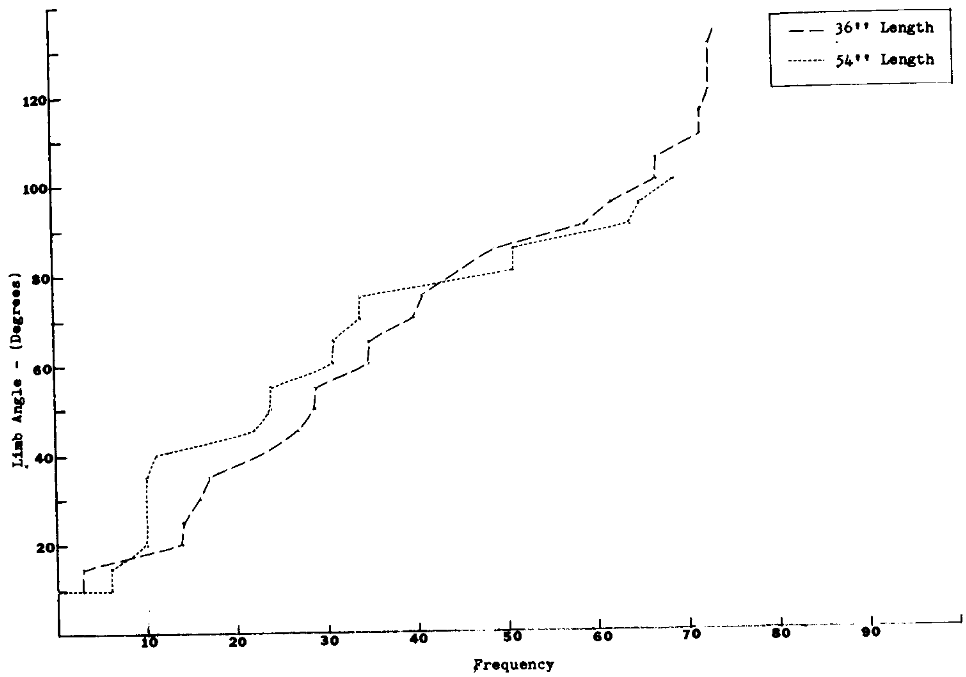
The Effect of Length Variation on Subtask Performance Time in a 48'' Airlock Direction O-C

Figure 4.2-23



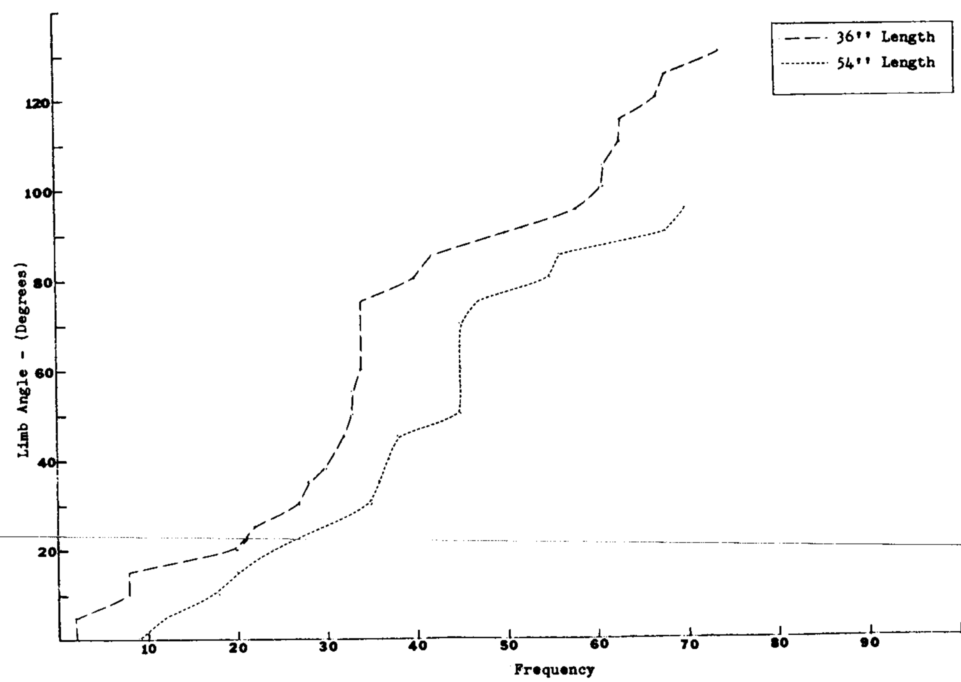
The Effect of Length Variation on Subtask Performance Time in a 48'' Diameter Airlock Direction C-O

Figure 4.2-24



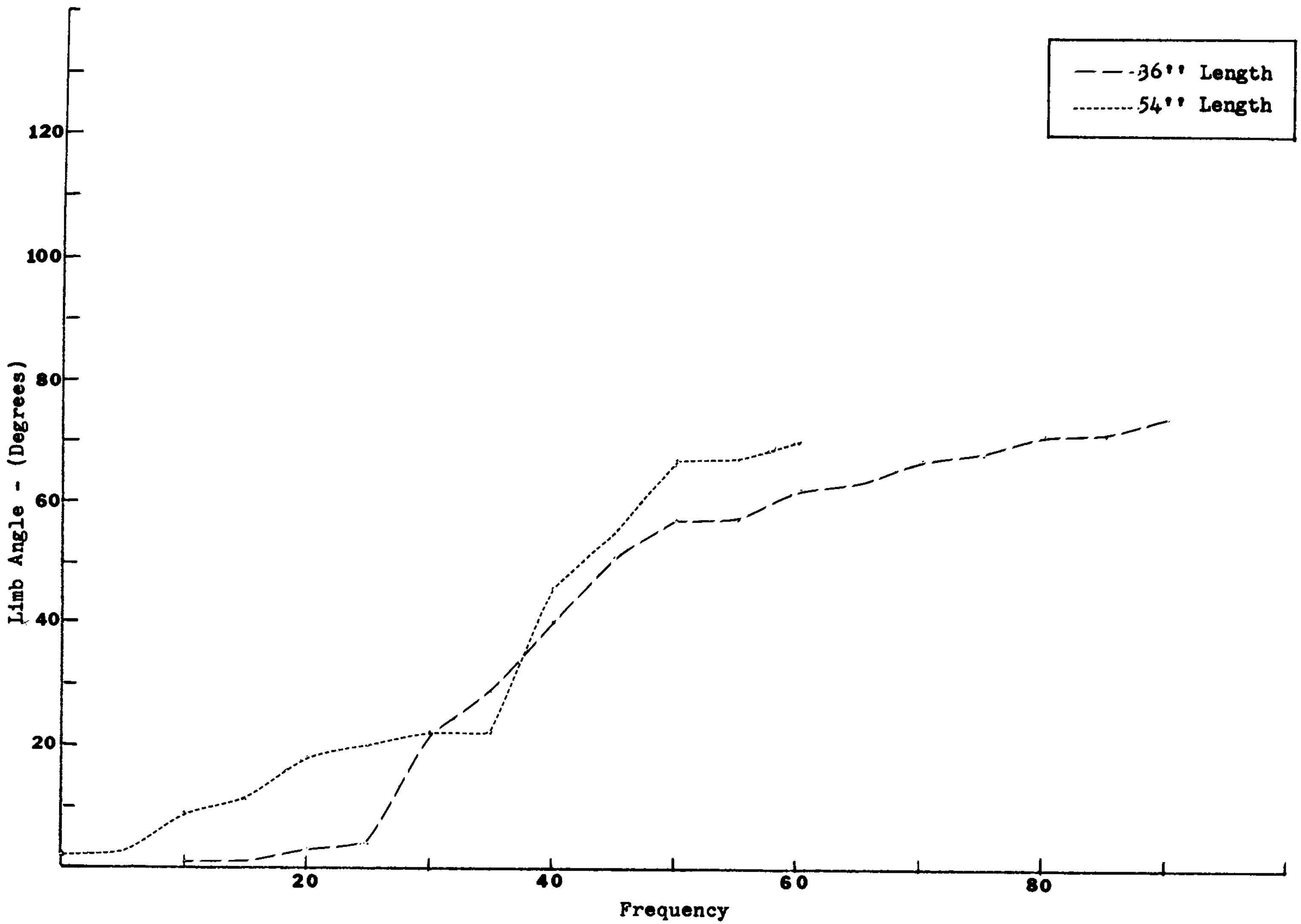
Limb Angle Frequency Profile, Elbow Angle For Entrance Through A Circular Door

Figure 4.2-25



Limb Angle Frequency Profile, Knee Angle For Entrance Through A Circular Door

Figure 4.2-26



Limb Angle Frequency Profile, Hip Angle For Entrance Through A Circular Door

Figure 4.2-27

4.2.6 NORMAL INGRESS-EGRESS AT SIMULATED ZERO GRAVITY VARIOUS DIAMETER AND LENGTH CYLINDRICAL AIRLOCKS

4.2.6.1 OBJECTIVES

This experimental task was established to expand the effort initiated in Task 7 to include a range of cylindrical airlock diameters. Five diameters were chosen for investigation; 24, 30, 36, 42, and 60 inches. Where possible three lengths were chosen for the investigation, one of which was the 72" length which was common to all versions. The procedure for each maneuver was the same as used for Task 7, except that one subject only was used and the maneuver was required to be performed three successive times without the aid of exit guide bar and/or safety tether.

Two additional sets of three successive maneuvers were performed for each of two length replications for each diameter airlock. The length variations used were chosen by the government project engineer after viewing the filmed performance of the 72" length.

4.2.6.2 PERFORMANCE THROUGH A 24" DIAMETER CYLINDRICAL AIRLOCK-Task 8

4.2.6.2.1 PERFORMANCE ANALYSIS-72" LENGTH

This maneuver was designed to be identical to the normal ingress-egress maneuver in the 48" airlock; however, the subject was unable to execute an entry into the airlock.

He began his attempt at this maneuver with his body perpendicular to the airlock axis. Holding onto the door frame with both hands, the subject aligned himself for entry. After determining the best orientation for entry, he began to enter the airlock. Once his head and upper chest entered the airlock, he was no longer able to make use of his hands, the only means of propulsion. This is shown in Figure 4.2-28.

After repeated attempts failed, a feet-first entry was tried to determine if the inability to enter was a function of the mode of entry. The same results occurred. The subject was able to maneuver into the airlock until his upper chest reached the entrance at which point he again lost his means of propulsion, the use of his hands.

4.2.6.2.2 PERFORMANCE ANALYSIS-REDUCED LENGTHS

Since the subject was unable to execute an entry into the 72" length airlock, no attempts were made to perform the ingress-egress maneuver at reduced lengths.

4.2.6.2.3 RESULTS

Task performance indicates that unassisted ingress-egress is not feasible in a 24" diameter airlock. Both the normal and modified modes of the ingress-egress were attempted and both were unsuccessful.

As a result of these tests, it is recommended that ingress-egress not be required in a 24" diameter airlock while wearing a full pressure suit at 3.5 PSIG.

The airlock used in the performance of this task did reveal one important characteristic. This airlock is relatively free of external appurtenances that could be used as handholds (i.e. protruding bolts, airlock support cables, exit bar, tether line). With this lack of handholds and the small hatchway, the subject found it very difficult to align himself for entry, indicating the need for such motion aids.

There should also be handholds supplied internal to the airlock with which the subject could pull himself into the airlock. It is possible that with more advanced full pressure suits that allow greater mobility, that the subject could have pulled himself through the airlock.

4.2.6.3 PERFORMANCE THROUGH A 30" DIAMETER CYLINDRICAL AIRLOCK-TASK 9

4.2.6.3.1 PERFORMANCE ANALYSIS-72" LENGTH-RUN 1

Elapsed Time: 0.0 Seconds

The maneuver began with the subject positioned perpendicular to the airlock axis. Holding onto the door frame with both hands, the subject maneuvered to a horizontal position. Grasping the top edge of the door frame with the left hand, he placed his head, right arm and shoulder inside the airlock. Using his left hand as the means of propulsion, he completed the entry.

Elapsed Time: 29.8 Seconds

Once inside the airlock, both of his arms were kept close to his body due to the confines of the airlock. Unable to turn around the subject continued the transit through the airlock using his hands and feet as the means of propulsion. Internal motion aids, such as handholds, would have compensated for the airlock constriction and loss of traction thus decreasing the transit time. Upon reaching the opposite end of the airlock the subject was able to exit with little apparent difficulty. A pictorial sequence of pertinent factors of the task performance is shown in Figure 4.2-29.

Elapsed Time: 93.7 Seconds-End of Maneuver

4.2.6.3.2 60" LENGTH

Since the subject was unable to execute a turnaround in this diameter airlock, no attempt was made to perform a turnaround at this reduced length. The purpose of these tests was to determine the minimum length at which a full pressure suited subject could encapsulate himself in a cylindrical airlock.

These test runs were performed at the 60" length. In Runs 1 and 2, the subject entered head first in the same manner as in the 72" length airlock. When his helmet made contact with the bulkhead, he pulled in his legs and wedged them between the airlock walls. It did not appear that the subject had any difficulty getting wholly within the airlock.

On the third run of this series of tests, the subject executed a feet-first entry. Except for the entry feet-first, there was no difference in the technique used by the subject to get himself completely within the confines of the airlock.

4.2.6.3.3 48" LENGTH

Four test runs were performed at this length. In the first three runs, the subject was able to complete the task using a head first entry but experienced considerably more difficulty as compared to the 60 inch length.

Using a feet-first entry on the final run, the subject was unable to completely enter the airlock. This was due primarily to the loss of gravity associated traction and lack of handholds. The subject was not able to enter quite far enough to make use of the airlock walls as a traction aid and was too far into the airlock to make use of any hardware on the airlock exterior. The film sequence depicting these runs are shown in Figure 4.2-29.

4.2.6.3.4 RESULTS

Task performance indicates that ingress-egress is feasible through a 30" diameter airlock; turnaround is not. Table VII shows representative times for the ingress, passage through and egress maneuvers.

TABLE VII

PERTINENT SUBTASK PERFORMANCE TIMES FOR INGRESS-EGRESS THROUGH A 30" DIAMETER AIRLOCK-ZERO GRAVITY SIMULATION

	Performance Times-Seconds			
Length	Ingress	Transit	Egress	Total
72"	29.8	15.0	17.0	61.8
60"	x	x	x	x
48"	x	x	x	x

°Average of three consecutive maneuvers of Subject A

x -indicates subtask maneuvers unsuccessful

As this table illustrates the ingress maneuver required nearly twice the time as egress. This time difference is due to the lack of external handholds for positioning. Also during exit from an airlock of this diameter, the subject was automatically aligned for exit.

The limb angle frequency profiles are shown in Figure 4.2-30 through 4.2-32. The magnitudes of these angles reveal that the arms are performing the propulsion, while the legs have been too restricted by the airlock walls to provide a large part of the propulsion.

Much of the subject's inability to maneuver within the airlock could be eliminated with the addition of internal handholds. This would have compensated for the loss of traction and smooth walls of the airlock.

4.2.6.4 PERFORMANCE THROUGH A 36" DIAMETER CYLINDRICAL AIRLOCK-TASK 10

4.2.6.4.1 PERFORMANCE ANALYSIS-72" LENGTH-RUN 1

Elapsed Time: 0.0 Seconds

The subject performed the entry into the 36" diameter airlock in the same manner as the entry into the 30" diameter airlock.

Elapsed Time: 27.3 Seconds

Once inside the airlock, a turnaround was attempted by the subject. After repeated attempts, it was decided that turnaround within the 36" airlock was unfeasible.

Elapsed Time: 66.4 Seconds

Failing to turnaround, the subject proceeded through the airlock, opened the door, exited and closed the door with little difficulty.

Elapsed Time: 104.0 Seconds-End of Maneuver

During the tests, one interesting performance variance was observed. On one run, the subject, realizing that he could not turnaround and close the door, reached outside the airlock and secured his foot under the door to pull it closed. Once the door was closed, the subject placed his feet on the latch handle and latched the door. Although it may be significant that he could close the door with his feet, two things must be remembered. The door was in the correct position to be closed with the feet and the latch does not require significant torque to secure the door.

4.2.6.4.2 60" LENGTH

As in the tests performed at reduced lengths in the 30 inch diameter airlock, no attempts were made to turnaround at the reduced lengths. The purpose was only to determine the minimum length in which the subject could encapsulate himself in the airlock.

Four test runs were made with the length at 60 inches with the subject entering through the outward opening door hatchway. The first two runs were made using a head-first entry. The subject was able to complete the maneuver by doubling up his legs to complete the entry with very little difficulty.

On the third run, the subject was able to pull the door closed and latch it with his feet after completing the entry.

The final run was made employing a feet-first entry. The subject was able to enter and close the door without any difficulty.

4.2.6.4.3 48" LENGTH

Three test runs were performed in this series using a 48" long airlock. The first two runs employed a head-first entry and was successfully completed; however, the subject was unable to close the door. The final run employed a feet-first entry. The subject was able to complete his entry but was again unable to close the door. His helmet did not enter far enough to clear the door latch mechanism during door closure. Figure 4.2-33 is a pictorial performance sequence for these maneuvers.

4.2.6.4.4 RESULTS

Test results have shown that while ingress-egress is feasible, turnaround within a 36" airlock is not. Table VIII shows the average times obtained during the time/motion study.

TABLE VIII

SUBTASK PERFORMANCE TIMES FOR INGRESS-EGRESS THROUGH A 36" DIAMETER AIRLOCK-72" LENGTH-ZERO GRAVITY SIMULATION

Subtask Description	Performance Times-Seconds
1. Open hatch (1)	5.5
2. Ingress	21.8
3. Transit	8.8
4. Open hatch (2)	10.8
5. Egress	8.9
6. Close hatch (2)	15.5
Total	71.3
°Average of three consecutive runs-Subject A	

This table shows that the ingress time is still relatively large compared to the ingress maneuver for the 48" airlock; nearly 34% longer. On the other hand, the egress maneuver also required more time than the maneuver in the 48" airlock.

The increase in time for the ingress maneuver was due to the increased demand for pre-alignment during entry and the lack of external motion aids. The increase in egress time, of 14%, was also due to the lack of external motion aids onto which the subject could hold during exit.

Figures 4.2-34 through 4.2-36 show the frequency distribution of the angle of bend at the elbow, hip and knee. Table IX shows the mode and average values for the limb flexure angles.

TABLE IX

MODE AND AVERAGE LIMB FLEXURE ANGLES FOR INGRESS-EGRESS THROUGH A 36" DIAMETER AIRLOCK 72" LENGTH

	Limb Angles - Degrees		
	Elbow	Hip	Knee
Mode	90	50	60
Average	74	65	56

°Average of three consecutive runs-Subject A

4.2.6.5 PERFORMANCE THROUGH A 42" DIAMETER CYLINDRICAL AIRLOCK-TASK 11

4.2.6.5.1 PERFORMANCE ANALYSIS-72" LENGTH-RUN 1

Elapsed Time: 0.0 Seconds

This maneuver began with the subject positioned perpendicular to the airlock axis, holding onto the edge of the door frame. Unlatching the door and pushing it open, entry was initiated by the subject.

Elapsed Time: 12.3 Seconds

Once inside the airlock, he made several attempts to turnaround. Being unsuccessful, he moved towards the outward opening door and used the latch handle as a traction aid. This maneuver enabled him to complete the turnaround. (Figures 4.2-37)

Elapsed Time: 73.0 Seconds

After closing the door, the subject again experienced difficulty in turning around.

The turnaround was executed by the subject wedging himself in the airlock using the inward opening door as an aid. Using his hands to pull his legs up under him, he was able to pivot, complete the turnaround maneuver.

Elapsed Time: 119.9 Seconds

Unlatching the door and pushing it open, the subject exited the airlock turned around and closed the door.

Elapsed Time: 213.9 Seconds-End of Maneuver

Because of the difficulty experienced in the turnaround maneuver, the subject attempted to turnaround using a different technique on his return passage. Once inside the airlock, he executed a forward somersault to accomplish the turnaround. (Figure 4.2-37). The subject then proceeded to complete the remainder of the maneuver using the somersault turnaround when required. The use of this technique produced a reduction in elapsed time of 34.8 seconds. The difficulties experienced in the turnaround maneuver are caused by three factors:

(a) loss of traction
(b) lack of internal handholds
(c) airlock diameter

Items (b) and (c) are closely related to the loss of traction.

In the larger diameter airlocks, the subject was able to bend his body sufficiently to wedge himself between the cylindrical walls of the airlock and compensate for the loss of traction. However, in the 42" diameter airlock, this was not possible and coupled with the lack of internal handholds, the turnaround became very difficult.

When the maneuver was performed in the reduced lengths airlocks, the subject had much less difficulty turning around. He was able to push against the end panels and wedge himself against the airlock walls. As the airlock length was decreased from 72" to 48", for example, the turn-around time decreased by 31%.

4.2.6.5.2 60" LENGTH

Three runs were made with the bulkhead five feet from the end in which the subject opened the door, entered, turnaround, closed the door, opened the door, exited and closed the door. The performance at this length followed the same procedures as in the full length airlock described above. The somersault movement was used for the turnaround maneuver. While this maneuver was successful for each run, the subject was delayed somewhat in turning around if he started too close to the door. The air tank interacted the door mechanism as he rolled head over heels.

4.2.6.5.3 48" LENGTH

Two runs were made at this length. The first run was successful but there was evidence of considerable force on the bulkhead while making the somersault turnaround. During the second run, the force on the bulk-head was sufficient to force out the 24" disc which filled the center section of the bulkhead, secured by several large wood screws. No further runs were made with this airlock due to safety considerations since the four foot length proved to be the minimum length that could be used.

4.2.6.5.4 RESULTS

Results of the time/motion study for this task may be extracted from Figures 4.2-38-4.2-39. These figures show the average time required to perform the subtasks. The average was obtained using the times of the second and third runs. Run 1 was intended as a learning period for the subject.

The figures indicate that the subtasks require a longer time to perform than similar performance with the 48" airlock. There was an increase of 60% in total performance time over the task performance time in the 48" airlock.

An attempt was made to determine if learning was a significant factor affecting the task performance times. A preliminary analysis of the data revealed that the turnaround maneuver would reveal the learning effect. Because the airlocks were equipped with an inward opening and outward opening door, the individual turnarounds would depend on whether the doors were open or closed. To compensate for this the average time for the two turnarounds per direction of travel were used. The results of these three runs are shown in Figure 4.2-40. It was found that for the 48" airlock and larger the statistical fluctuations in the values were so large as to obscure any effects that could be attributed to learning, Figure 4.2-40. The frequency distributions for the flexure of the elbow, hip and knee are shown in Figures 4.2-41-4.2-43. The values of the mode sizes and average of the graphs are given in Table X.

TABLE X

MODE AND AVERAGE LIMB FLEXURE ANGLES FOR INGRESS-EGRESS THROUGH A 42" DIAMETER AIRLOCK-72" LENGTH

	Limb Angles - Degrees		
	Elbow	Hip	Knee
Mode	70	50	40
Average	71	37	51

Tests were also performed to determine the minimum length required to turnaround. From the film analysis, it was decided to place a bulkhead a distance 4 feet and 5 feet from the outward opening door. It was determined that the subject could turnaround in the airlock at these two reduced lengths. The tests revealed that the subject was able to turnaround in minimum time for the four foot length airlock. This was accounted for by the associated loss of traction in a neutrally buoyant condition and the lack of internal handholds. The subject found the diameter was small enough that he had great difficulty getting himself wedged between the walls without assistance. As the length was shortened, he was able to push against the bulkhead and end panel to wedge himself between the airlock walls to provide the traction needed for the turnaround.

4.2.6.6 PERFORMANCE THROUGH A 60" DIAMETER CYLINDRICAL AIRLOCK-TASK 12

4.2.6.6.1 PERFORMANCE ANALYSIS-72" LENGTH-RUN 1

Elapsed Time: 0.0 Seconds

This maneuver was performed following the same procedure as the normal ingress-egress in the 48" airlock. The task began with the subject positioned perpendicular to the airlock axis, facing the inward opening door. After unlatching and pushing the door open, the subject began his entry.

Elapsed Time: 6.0 Seconds

With very little apparent difficulty, the subject pulled himself into the airlock. The ease of entry was attributed to the large diameter airlock and the decreasing requirement for exact pre-positioning during entry. (Figure 4.2-44).

Completing the entry, the subject made his turnaround and closed the door.

Elapsed Time: 26.7 Seconds

After closing the door, the subject again made a turnaround to face the outward opening door. The turnaround times for the subject during the performance of this task were enhanced by the large diameter of the airlock. (Figure 4.2-44). This resulted in an average decrease in turnaround time of 53% over the 48" diameter airlock.

Elapsed Time: 31.3 Seconds

Unlatching the door and pushing it open, the subject then made his exit from the airlock, turned around and closed the door.

Elapsed Time: 58.8 Seconds-End of Maneuver

4.2.6.6.2 24" LENGTH

The tests in this series were run with an airlock length of 24 inches; the subject was able to enter through the outward opening door hatchway, turnaround and close the door with considerable difficulty. After opening the door to perform the exit, the subject found that he could not egress from the airlock. As his head passed through the hatchway, his air bottle interacted the hatch opening and he was unable to free himself. Following repeated attempts, the subject appeared to become frustrated and was removed from the airlock by the safety men. No further ingress-egress attempts were made at this length.

4.2.6.6.3 36" LENGTH

The runs were made at this length using the outward opening door. The subject did not experience any difficulty in completing the entire ingress-egress maneuver. One run was also performed using the inward opening door. While the subject successfully completed the maneuver, it was evident from the difficulty experienced during the turnaround and door closure that this was the minimum length with an inward opening door.

4.2.6.6.4 48" LENGTH

Three runs were performed employing a head first entry and exit using a length of 48 inches. There was no difficulty experienced in the performance of these runs. The additional length removed the interference caused by the door-swing and interaction with associated hardware.

4.2.6.6.5 RESULTS

The results of the time-motion study are shown in Figures 4.2-38-4.2-39 and show that the subtask performance times for the 60 inch diameter airlock were smaller than those for the smaller diameter airlocks. This decrease in time can be attributed to the entry and turnaround maneuvers. Figure 4.2-44 is a pictorial sequence depicting performance in the 60" diameter airlock.

The entry maneuver required 56% less time than the same maneuver in the 48 inch airlock. The time required for the entry maneuver is a function of the diameter of the airlock, and the pre-alignment necessary for entry. During the performance of the tests it was observed that, in this size airlock, the subject was not required to enter as parallel to the axis of the airlock as in the 48 inch and smaller diameter airlocks. This allowed greater pre-alignment error and consequently shorter ingress time.

The turnaround averaged 53% less time in this airlock as compared to the 48 inch diameter airlock. This was a result of the fact that the subject was required to make much smaller suit compressions during the turnaround.

In contrast to the relatively large decrease in ingress and turnaround times, egress time was 4% greater than the exit time in the 48 inch airlock. Although this difference is probably not significant, there is a difference of only 8% between the total ingress and egress times in the 60 inch diameter airlock, whereas in the 48 inch diameter airlock, this difference amounts to 46%. This is accounted for by the inability to pre-align during egress. Thus, the entry and exit become less differentiable.

To determine the minimum length to turnaround, a bulkhead was placed 2 feet, 3 feet and 5 feet from the outward opening door. In the attempts to turnaround in a reduced length airlock, it was found that the subject could enter and turnaround in a 24 inch long airlock. However, he was unable to exit after the turnaround. The exit could have been accomplished if motion aids were placed inside the airlock to aid the subject compress his suit enough to exit or a door opening larger than 32 inch diameter was used. The subject experienced no performance difficulties at the three and five foot lengths.

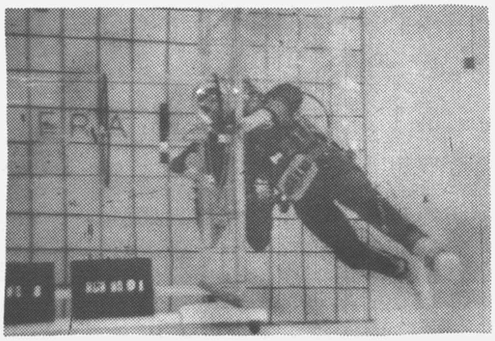
For the 3 foot length, the subject had no difficulty completing the entire maneuver. Also, at this reduced length the turnaround time decreased slightly from the full length airlock, nearly 15%. Figures 4.2-45-4.2-47 show the frequency distribution of the degree of bend at the elbow, hip, and knee for the 72 inch long airlock. The mode and average size are shown in Table XI.

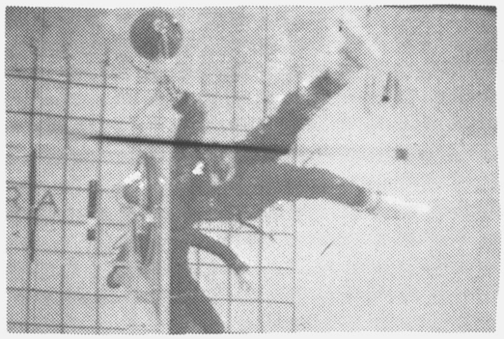
TABLE XI

MODE AND AVERAGE LIMB FLEXURE ANGLES FOR INGRESS-EGRESS THROUGH A 60" DIAMETER AIRLOCK-72" LENGTH

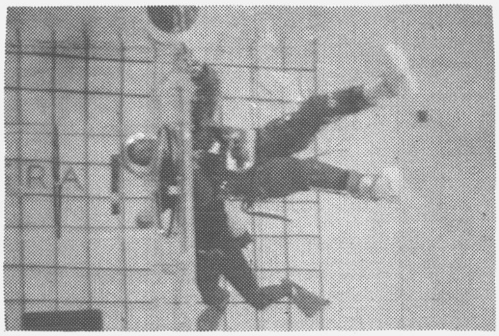
	Limb Angles - Degrees		
	Elbow	Hip	Knee
Mode	80/90	40	50
Average	71	37	51

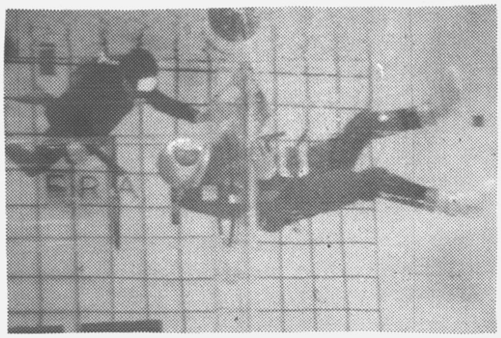
These values indicate that the ingress-egress task in a 60 inch diameter airlock required more use of the arms than of the legs. This is to be expected since the diameter of the airlock has decreased to the point at which the subject had to wedge himself between the walls to perform a turnaround. Therefore, since his hands provide a better means of positioning than the legs, the arm bend at the elbow is large compared to the bend at the hip and knee.





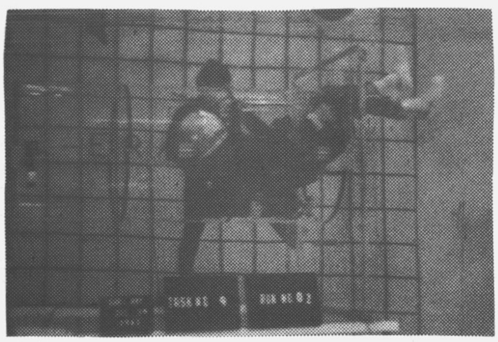
Attempt To Enter





Attempt To Enter

4.2-28 Sequence Of Ingress-Egress Maneuvers Through A 24" Diameter Cylindrical Airlock - Task 8



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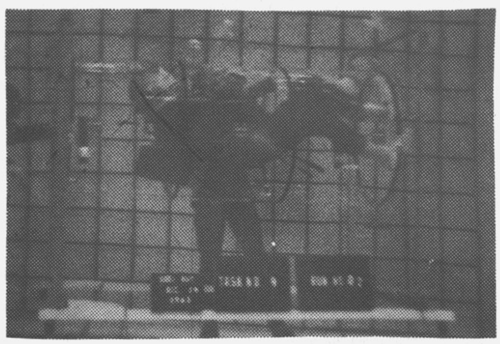
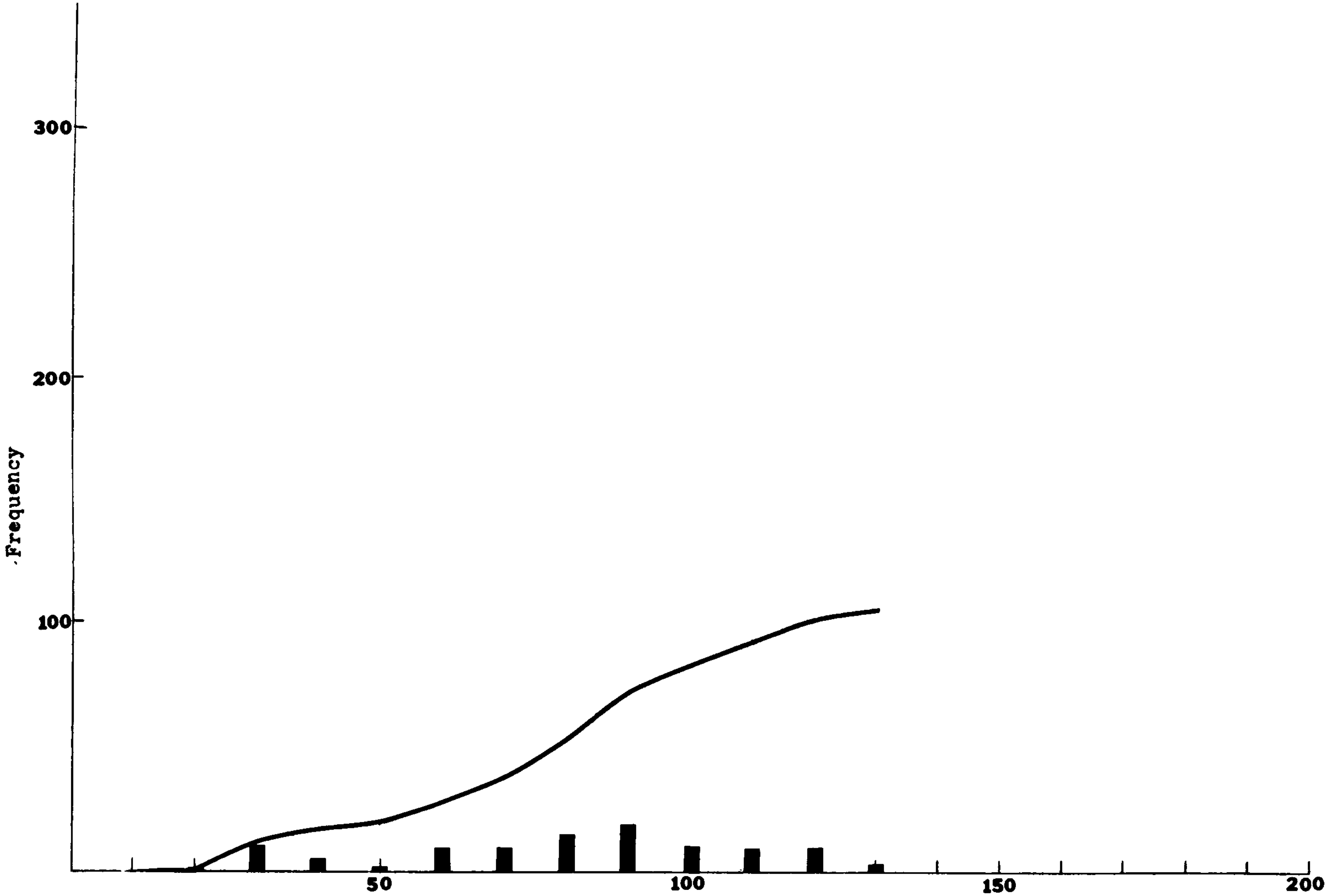


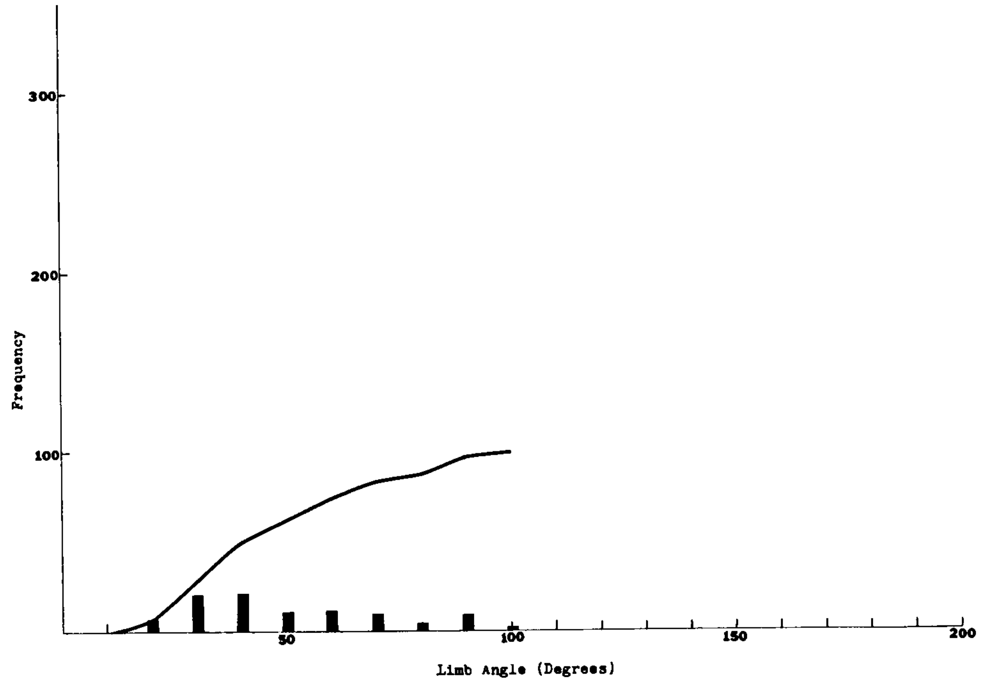
Attempt To Turnaround

4.2-29 Sequence Of Ingress-Egress Maneuvers Through A 30" Diameter Cylindrical Airlock - Task 9



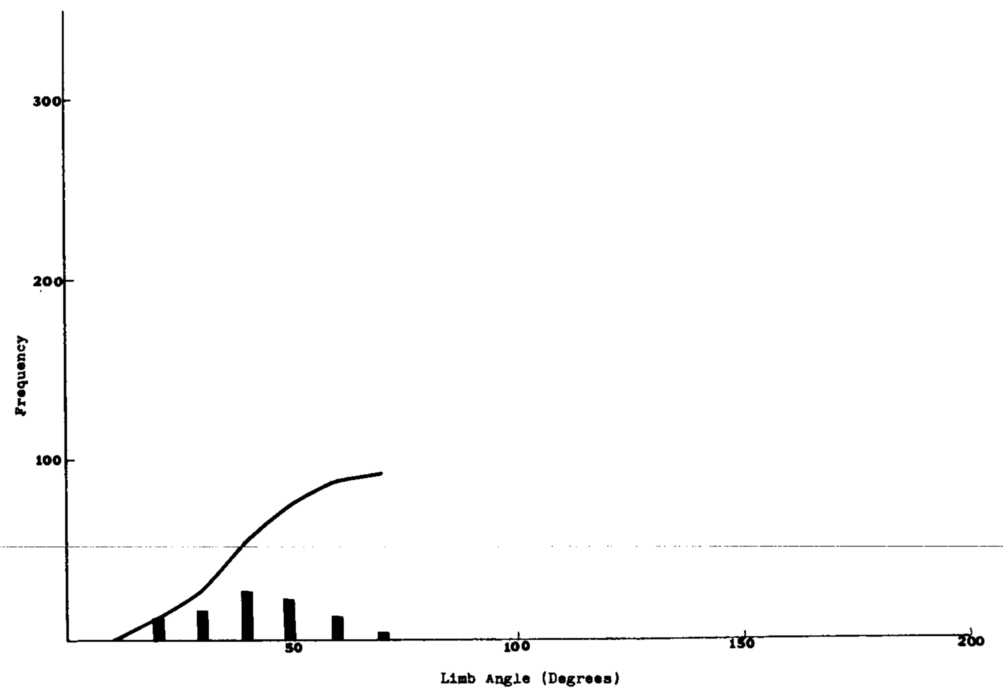
Limb Angle Frequency Profile - Elbow Angle - Subject A - Task 9/Run 2

Figure 4.2-30



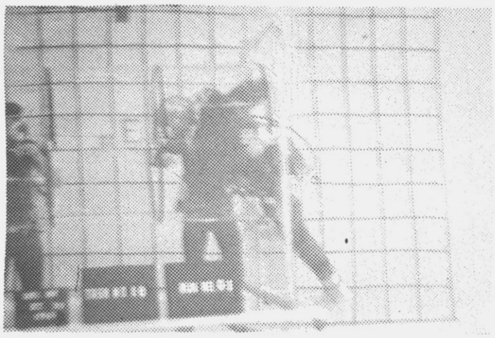
Limb Angle Frequency Profile - Knee Angle - Subject A - Task 9/Run 2

Figure 4.2-31



Limb Angle Frequency Profile - Hip Angle - Subject A - Task 9/Run 2

Figure 4.2-32



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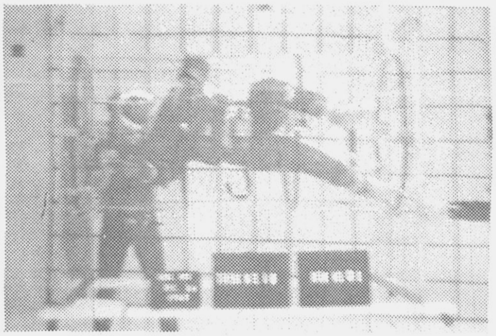
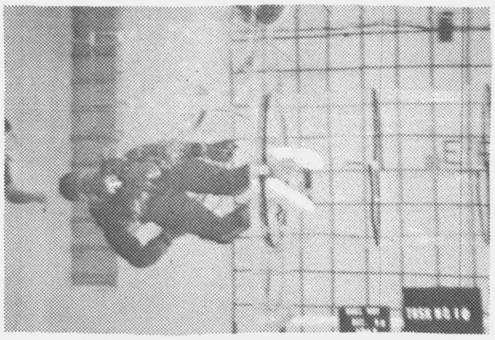
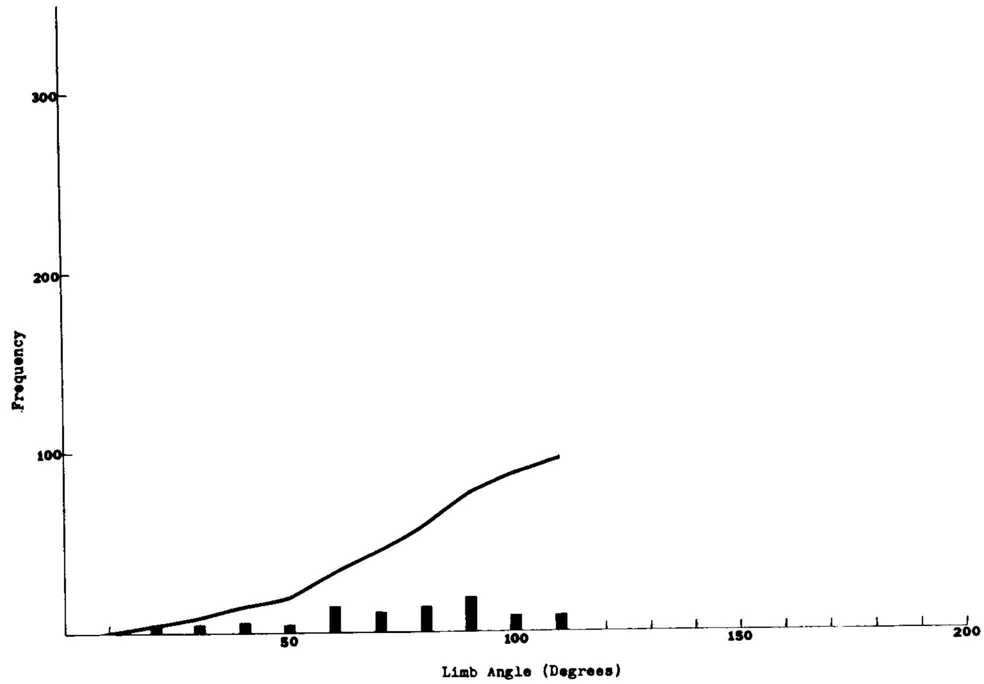


Attempt To Turnaround



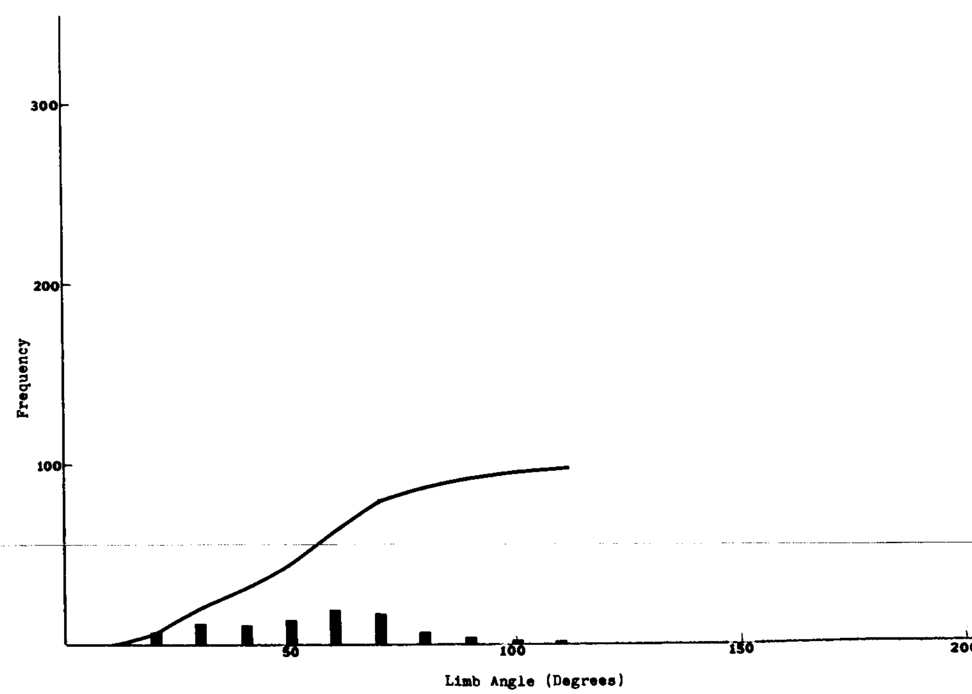
Exit

4.2-33 Sequence Of Ingress-Egress Maneuvers Through A 36" Diameter Cylindrical Airlock - Task 10



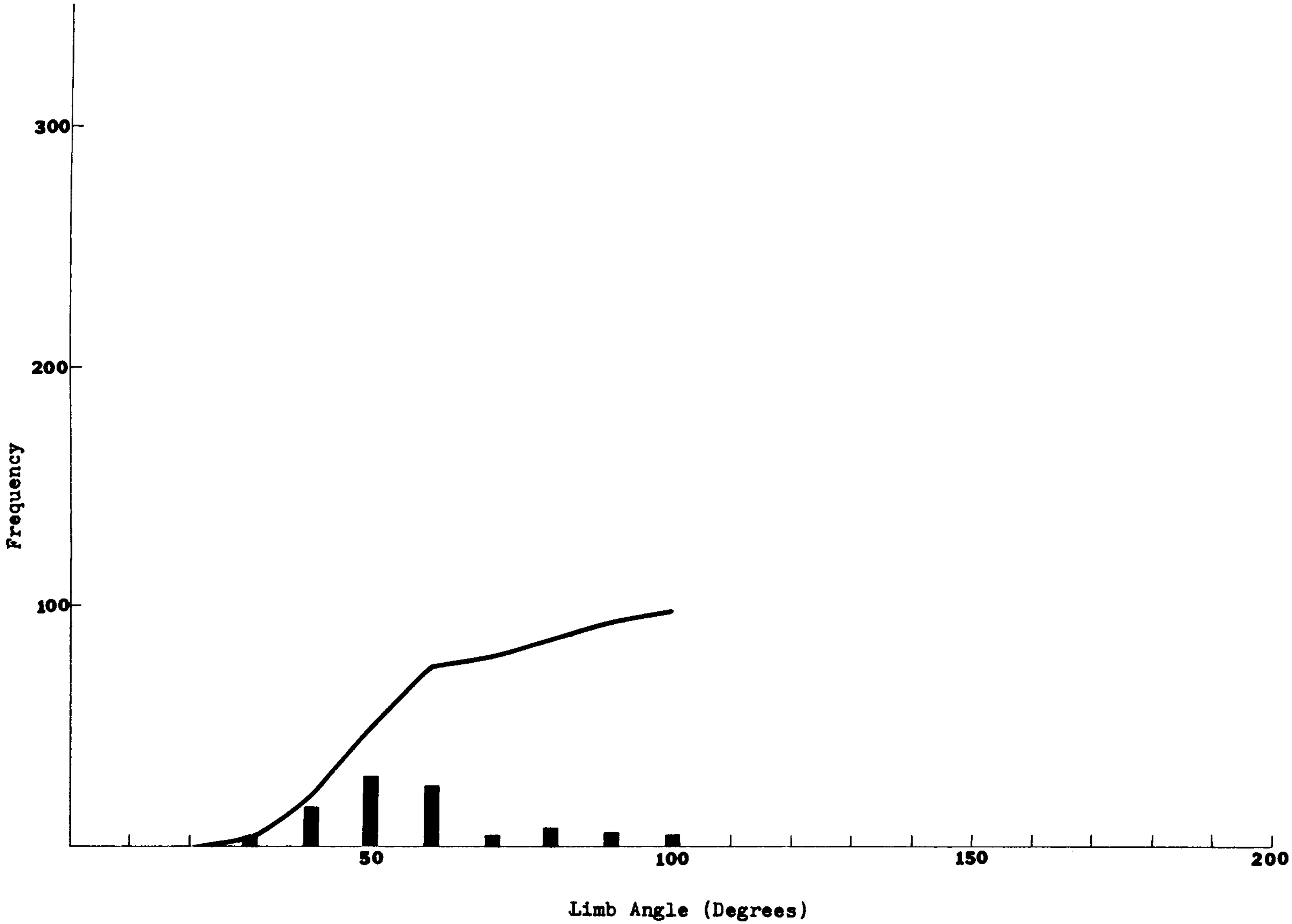
Limb Angle Frequency Profile - Elbow Angle - Subject A - Task 10/Run 2

Figure 4.2-34



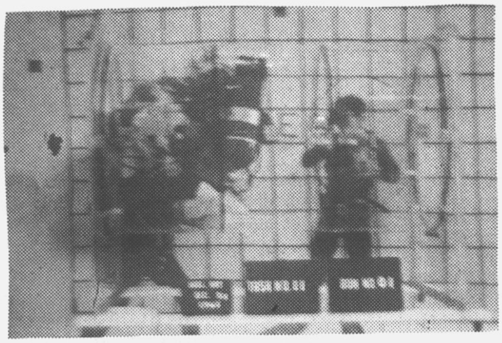
Limb Angle Frequency Profile - Knee Angle - Subject A - Task 10/Run 2

Figure 4.2-35

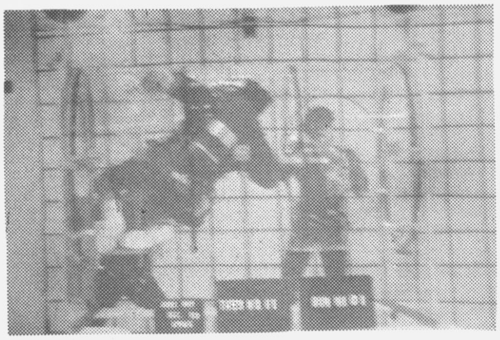


Limb Angle Frequency Profile - Hip Angle - Subject A - Task 10/Run 2

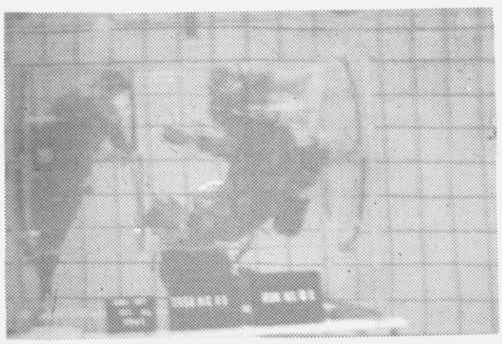
Figure 4.2-36



Turnaround (1)

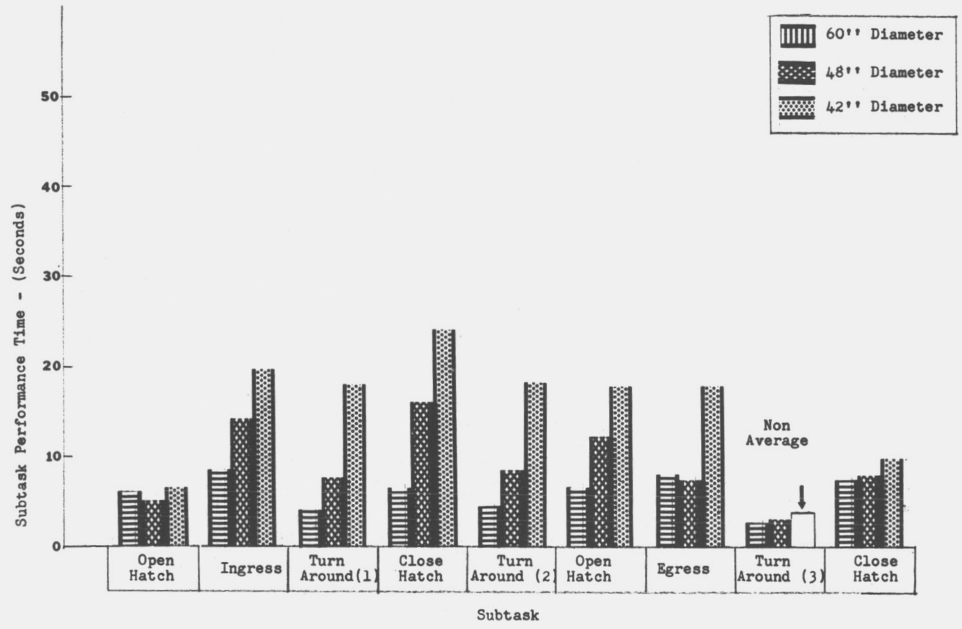


Turnaround (2)



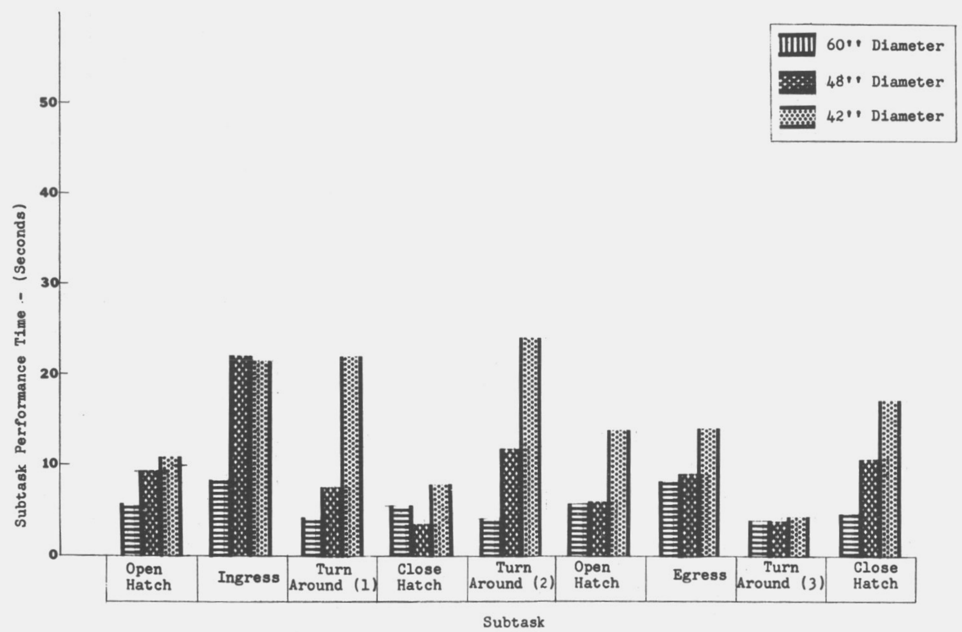
Sommersault Turnaround

4.2-37 Sequence Of An Ingress-Egress Maneuver Through A 42" Diameter Cylindrical Airlock - Task 11



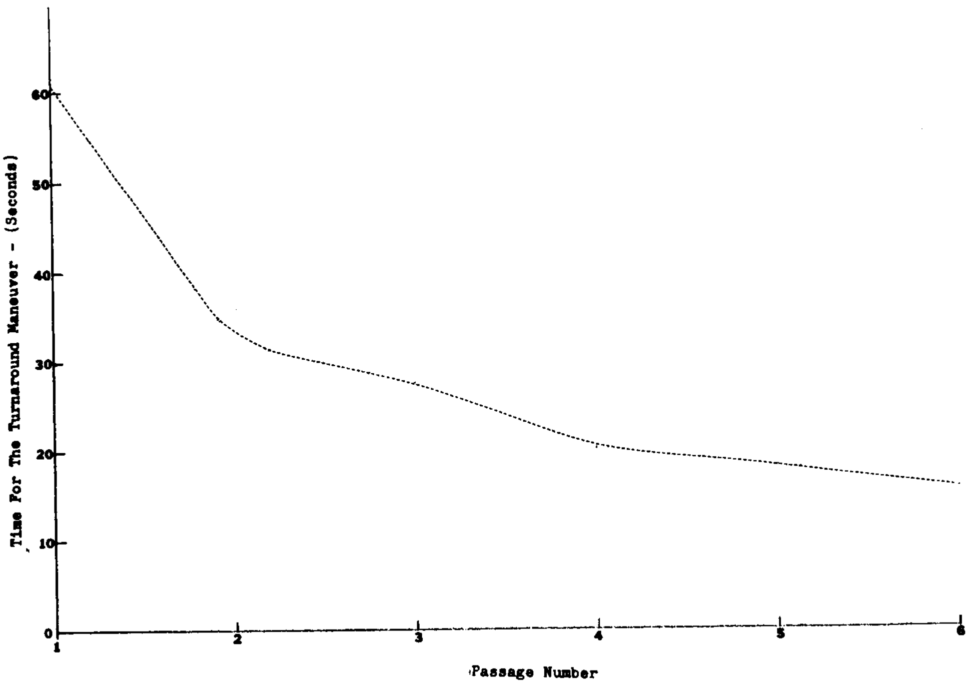
The Effect of Diameter Variation on Subtask Performance Time in a 72'' Length Airlock
Subject A, Direction O-I

Figure 4.2-38



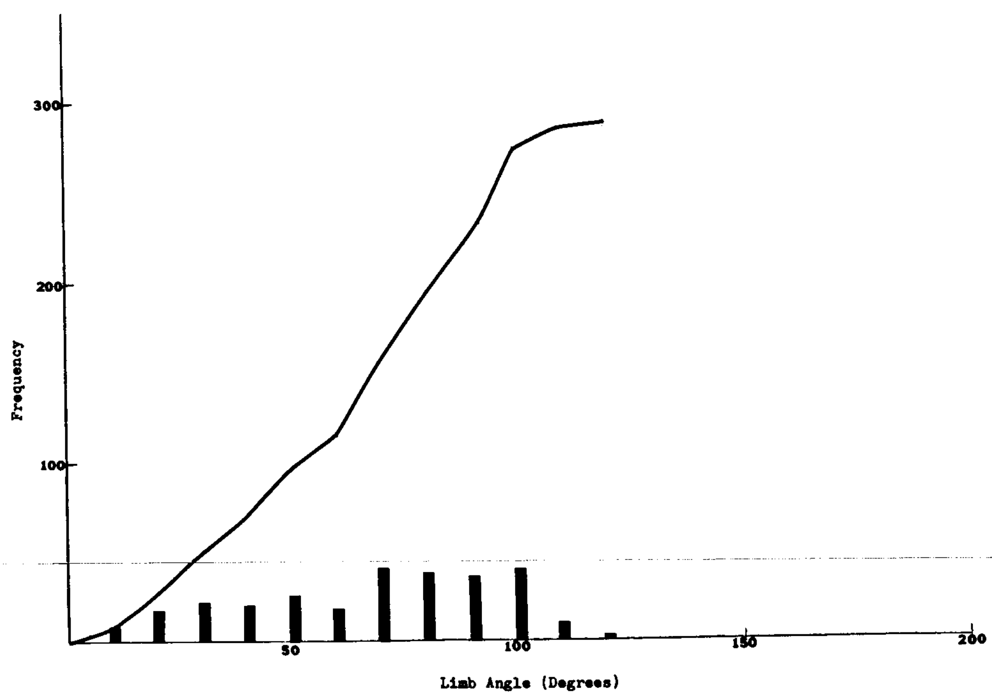
The Effect of Diameter Variation on Subtask Performance Time in a 72'' Length Airlock
Subject A Direction I-O

Figure 4.2-39



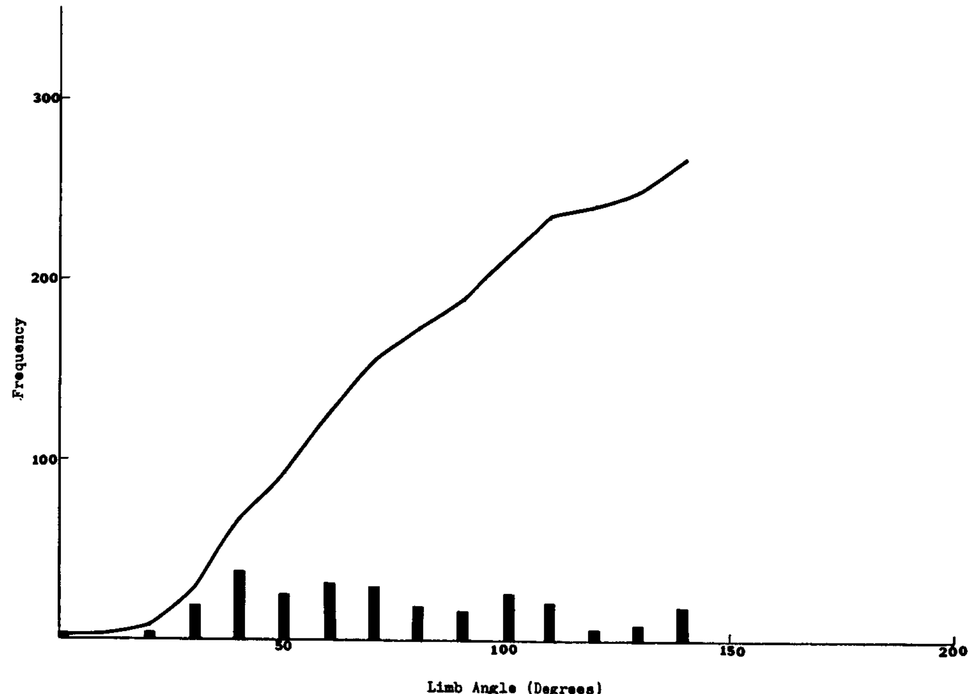
Average Time for the Turnaround Maneuver for Successive Passages Through the Airlock
Subject A Simulated O-G 42'' Diameter Airlock 72'' Length

Figure 4.2-40



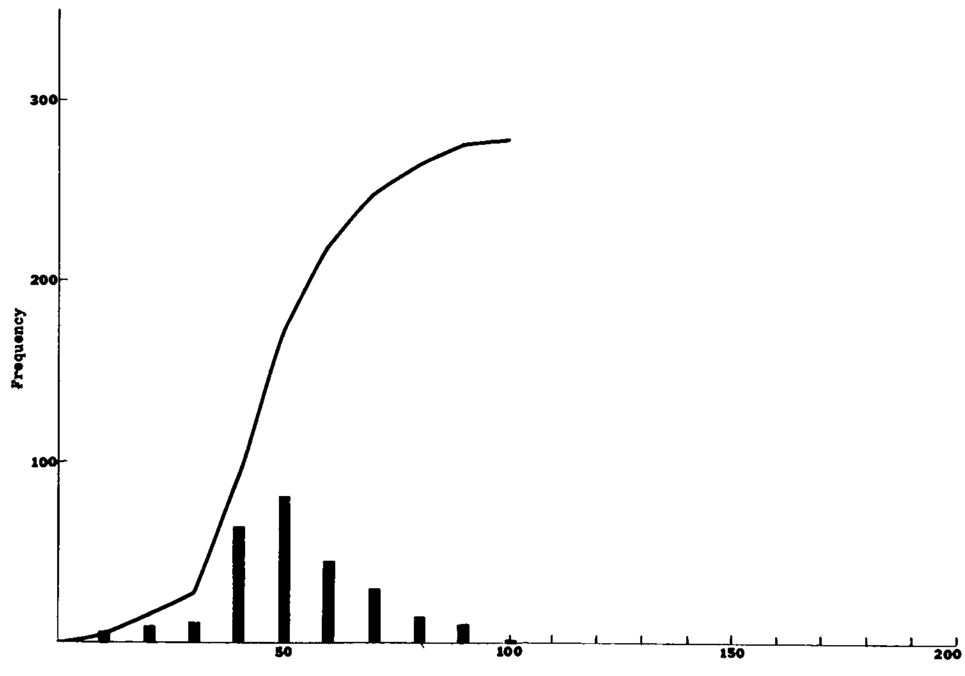
Limb Angle Frequency Profile - Elbow Angle - Subject A - Task 11/Run 2

Figure 4.2-41



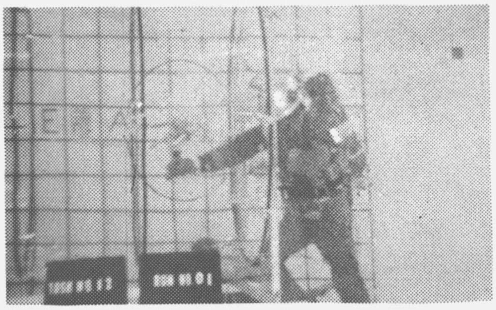
Limb Angle Frequency Profile - Knee Angle - Subject A - Task 11/Run 2

Figure 4.2-42

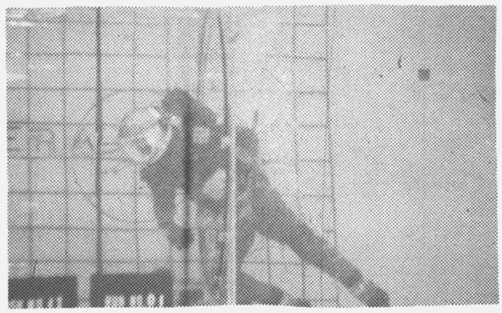


Limb Angle Frequency Profile - Hip Angle - Subject A - Task 11/Run 2

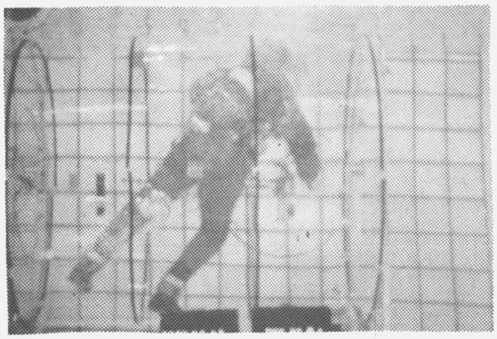
Figure 4.2-43



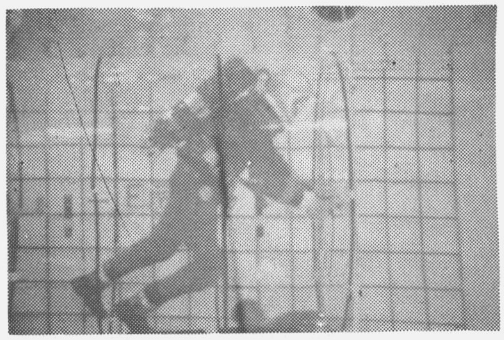
Open Door



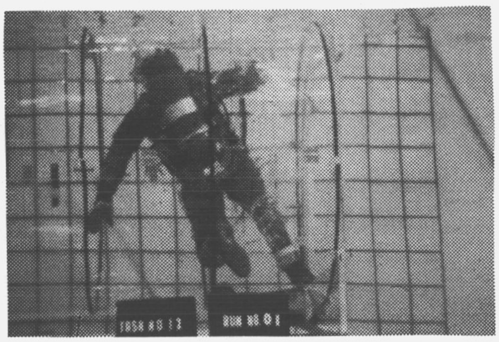
Ingress



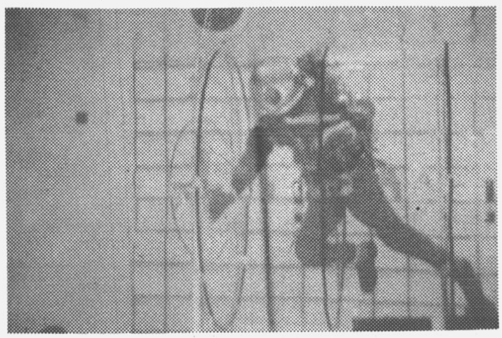
Turnaround



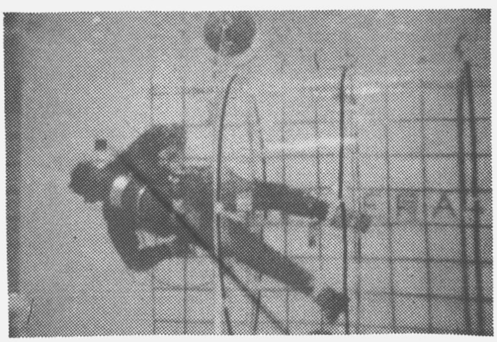
Close Door



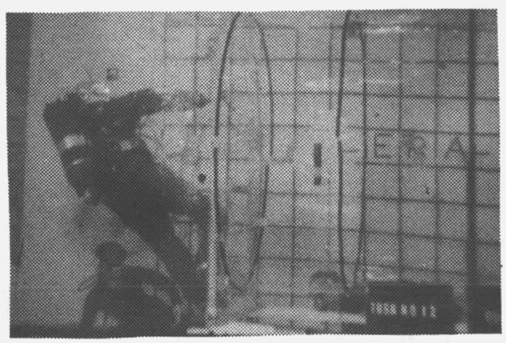
Turnaround



Open Door

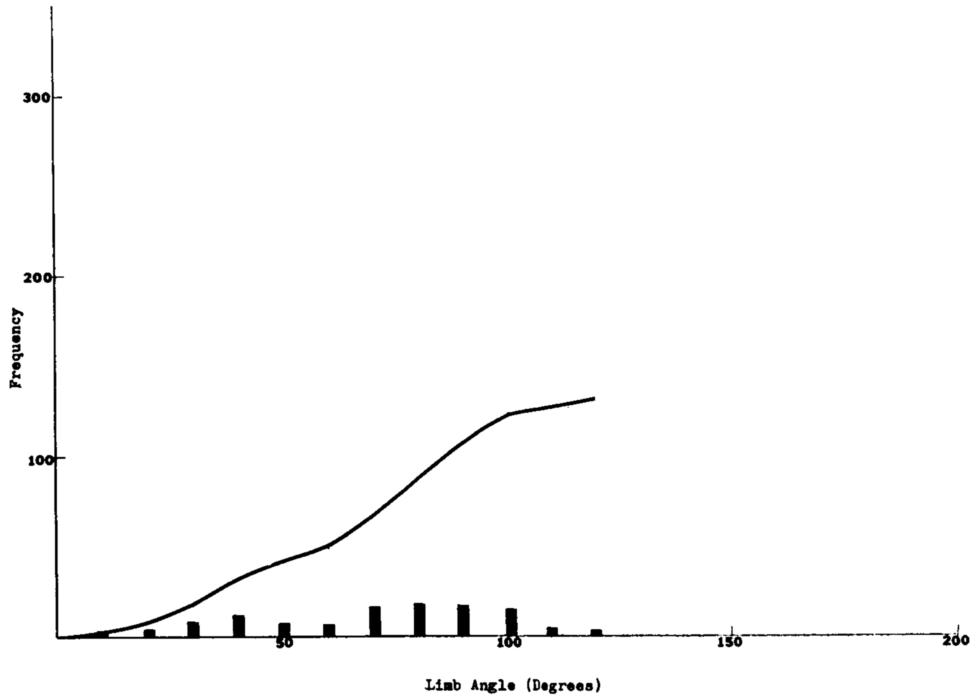


Egress



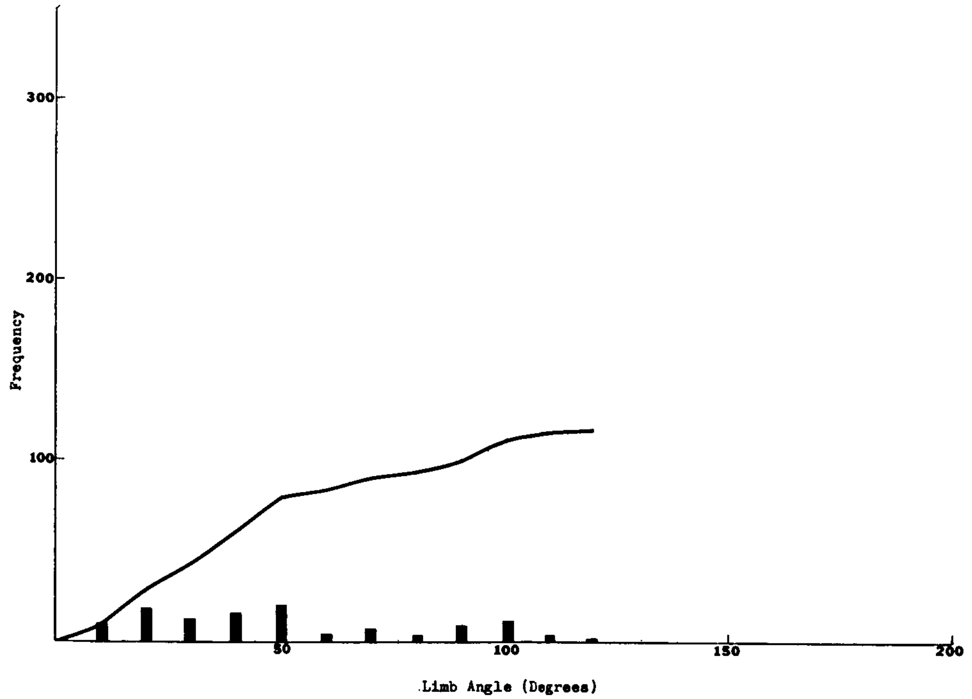
Close Door

4.2-44 Sequence Of Ingress-Egress Maneuvers Through A 60" Diameter Cylindrical Airlock - Task 12



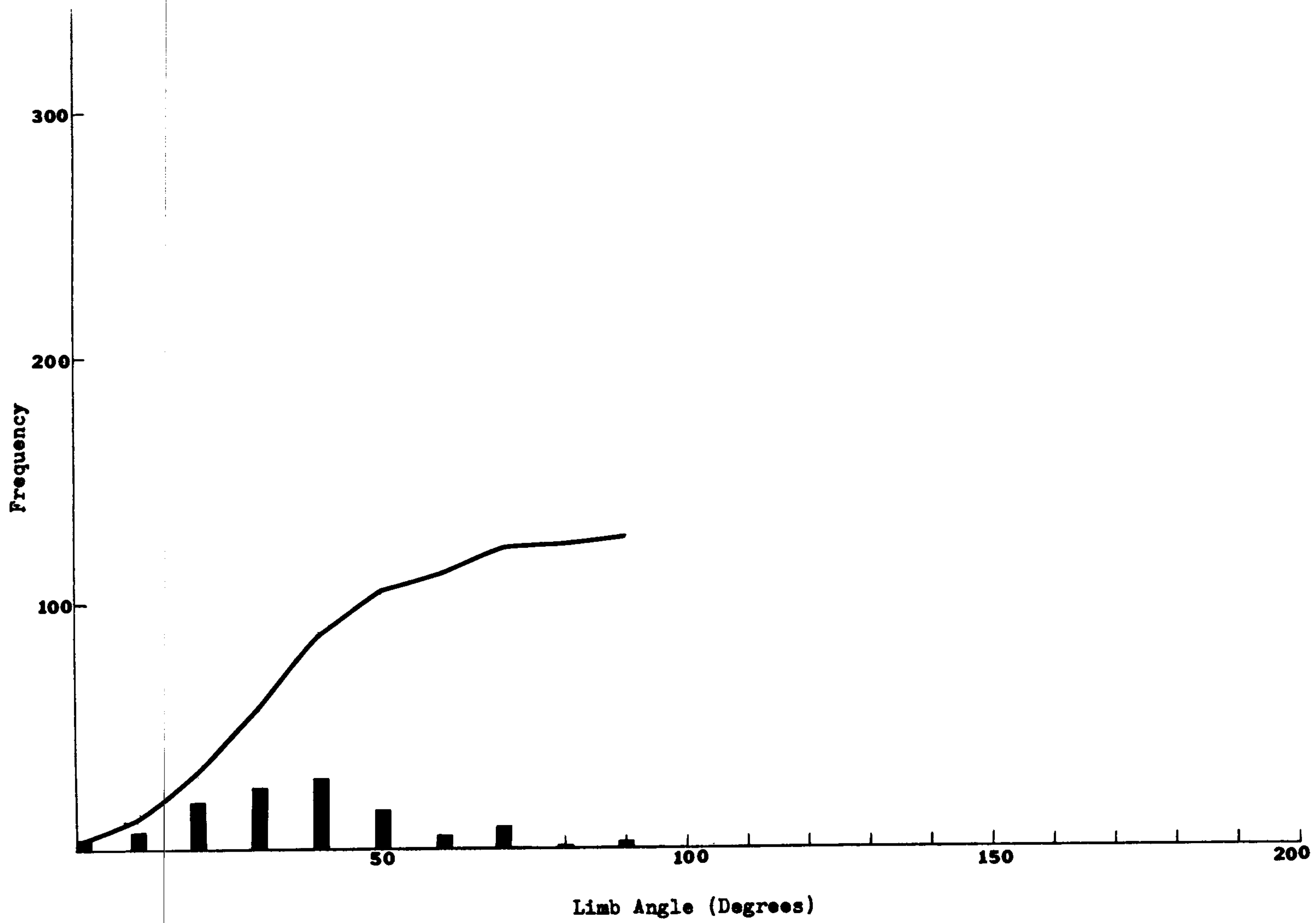
Limb Angle Frequency Profile - Elbow Angle - Subject A - Task 12/Run 1

Figure 4.2-45



Limb Angle Frequency Profile - Knee Angle - Subject A - Task 12/Run 1

Figure 4.2-46



Limb Angle Frequency Profile - Hip Angle - Subject A - Task 12/Run 1

Figure 4.2-47

4.2.7 INGRESS-EGRESS AT SIMULATED 0.08 AND 0.16 G_e THROUGH A 48" DIAMETER CYLINDRICAL AIRLOCK-6' LENGTH

4.2.7.1 OBJECTIVES

Concomitant with the requirement to ingress-egress airlocks while in a zero-gravity environment, future astronauts will also be faced with the performance of similar task at various gravity levels. Particularly important for the establishment of bases on other planets, this performance induces other restrictions than experienced for the zero-gravity ingress-egress. For example, door hatch placement relative to airlock floor level and the location of hardware in relation to the floor of the airlocks assume importance. This task was introduced to primarily assess the differences and characteristics of airlock operation at 0.08 and 0.16 G_e levels.

The subject wearing an Arrowhead, Mark IV-FPS, pressurized to 3.5 PSI above ambient performed the normal and modified ingress-egress maneuvers previously described in section 4.2.3.1. and 4.2.4.1 through the 48 inch diameter, 6 foot long airlock in a manner similar to the zero-gravity maneuvers.

4.2.7.2 NORMAL INGRESS-EGRESS AT SIMULATED REDUCED GRAVITY LEVELS-TASK 13

4.2.7.2.1 PERFORMANCE ANALYSIS-0.16G - RUN 1

Elapsed Time: 0.0 Seconds

The performance of the task began with the subject positioned exterior to the airlock, facing the oval door. Using his left hand to support himself with the exit bar, he unlatched and pushed the door open. Placing both hands on the lower edge of the hatchway, the subject pulled himself into the airlock.

Elapsed Time: 14.7 Seconds

Once inside, the subject turned around and closed the oval door. After executing a second turnaround to face the circular door, the subject unlatched and pushed the door open.

Elapsed Time: 42.2 Seconds

Grasping the door handle with his right hand, the subject proceeded to make his head first exit. As his shoulders passed through the hatchway, he grasped the tether with his left hand. As he proceeded further, the tether did not provide support to keep him from falling out of the airlock. As he began to fall, he released his hold on the tether and placed his left hand on the floor for support. The subject executed a turnaround and closed the door to complete the egress.

Elapsed Time: 58.0 Seconds-End of Maneuver

A sequence of pertinent events is shown in Figure 4.2-48.

4.2.7.2.2-0.08 GRAVITY

The test runs at the simulated 0.08 gravity level were performed following the same procedures as in the 0.16 gravity case. The subject continued having difficulty while exiting the circular door since the tether line did not provide the support needed to prevent the subject from falling out of the airlock.

4.2.7.2.3 RESULTS

The results of the tests are depicted in Figure 4.2-49-4.2-50 and show the relationship of the normal ingress-egress maneuver at reduced gravity levels and the zero gravity condition.

Comparison of these figures with similar figures for the zero gravity case indicates that an increase in gravity level decreases the time needed to enter the airlock. The addition of a positive weight to the subject provided needed traction between him and the floor and augmented his prepositioning ability.

The egress time was not affected in the same manner as the ingress time. This was due to the manner of exit and the adaptability of the tether line and exit bar to the reduced gravity maneuvers. Because of his tendency to fall out of the airlock, the subject required a rigid support. The tether did not supply this support. Egress times using the exit bar required less time than egress using the tether line (Figure 4.2-48).

Figure 4.2-51 shows the total time for the performance of the task. Here it can be seen that the 0.08 gravity maneuver required less time than the neutrally buoyant condition and the 0.16 gravity level performance time less than both of these. Figures 4.2-52-4.2-57 show the frequency distribution for the angle of bend at the subject's elbow, hip and knee. Table XII lists the average and mode for these distributions.

TABLE XII

COMPARISON OF MODE AND AVERAGE LIMB FLEXURE ANGLES FOR VARIOUS SIMULATED GRAVITY LEVEL

Gravity Level		Limb Angles - Degrees Elbow	Hip	Knee
0 'G'	Average	74	16	60
	Mode	90	0	0
0.08 'G'	Average	60	35	75
	Mode	30	30	60
0.16 'G'	Average	62	39	79
	Mode	30	40	80
Average of Three Consecutive Runs of Subject A Through A 48" Diameter Airlock - 72" Length				

The variance of limb flexure angles is to be expected since the majority of maneuvering and positioning is accomplished by the use of the hands in the zero gravity condition. The hip and knee are left in a semi-relaxed position, except during the performance of tasks within the airlock. At the reduced gravity levels, the opposite is true. The hands are no longer the major means of maneuvering. The ability to apply traction enables the leg to be used for locomotion and positioning. This causes a resultant increase in the amount of bending at the hip and knee.

4.2.7.3 MODIFIED INGRESS-EGRESS AT SIMULATED REDUCED GRAVITY LEVELS-TASK 14

4.2.7.3.1 PERFORMANCE ANALYSIS-0.16 G-RUN 1

Elapsed Time: 0.0 Seconds

The performance of this task was initiated with the subject holding the exit bar with his left hand. Using his right hand, he unlatched the oval door and pushed it open. Grasping the upper edge of the hatchway with both hands, the subject lifted both feet off the floor and placed them into the airlock. As his body entered the airlock further, he released his grasp on the hatchway and grasped the door handle to pull himself in and complete the entry.

Elapsed Time: 20.5 Seconds

Completing the entry, the subject positioned himself facing the oval hatchway and pushed the door closed. Turning to his right, he completed the turnaround to face the circular door. Using his right hand, the subject unlatched and pushed the circular door open. Performing another turnaround, he was positioned to make his feet-first exit.

Elapsed Time: 46.9 Seconds

The subject initiated his exit by lifting his feet over the edge of the hatchway. Looking in the direction of his feet to be sure that they were clear of the edge of the hatchway, he pushed on the sides of the airlock to force himself out and complete the exit.

Elapsed Time: 55.4 Seconds

Using the tether line on which to pull while he pushed the door closed, the subject completed the maneuver. A sequence of pertinent events is shown in Figure 4.2-58.

Elapsed Time: 63.1 Seconds-End of Maneuver

4.2.7.3.2-0.08 GRAVITY

The test runs at the simulated 0.08 Gravity level were performed following the same procedures as in the 0.16 gravity level case. Three test runs were performed. On the first two runs the subject made his exit through the circular door while facing up. This caused him to have difficulty while passing over the edge of the hatchway. On both occasions, he snagged his air bottle on the edge. The third run was performed in the same manner as in the 0.16 gravity level case. The exit was with the subject facing up and no difficulty was experienced during the exit.

4.2.7.3.3 RESULTS

The results of the time-motion study are represented in Figures 4.2-59-4.2-60. It can be seen that at the reduced gravity level the performance times were always less than the zero gravity condition. Figure 4.2-61 shows the total performance time for this task performed at each gravity level. It reveals that the 0.08 gravity level requires less time for execution than either of the two other levels. This indicates that there may be an intermediate gravity level between $0G_e$ and $1G_e$ at which man is more efficient than at other levels in this range. This trend existed through all the reduced gravity tasks except the normal ingress-egress maneuver.

Figures 4.2-61-4.2-63 show the frequency distribution of limb bending for the 0.16 gravity level and are summarized in Table XIII.

TABLE XIII

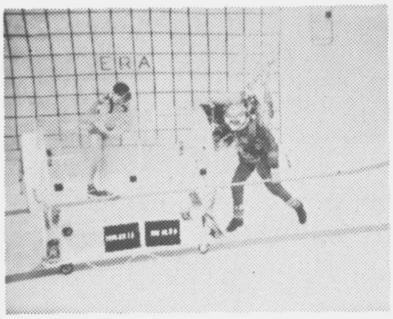
MODE AND AVERAGE LIMB FLEXURE ANGLES FOR MODIFIED INGRESS-EGRESS THROUGH A 48" DIAMETER AIRLOCK-72" LENGTH FOR REDUCED GRAVITY OPERATIONS

Gravity Level		Limb Angles - Degrees		
		Elbow	Hip	Knee
0° G_e	Average	76	26	63
	Mode	75	20	30
0.08 G_e	Average	NR	NR	NR
	Mode	NR	NR	NR
0.16 G_e	Average	63	43	76
	Mode	90	40	100

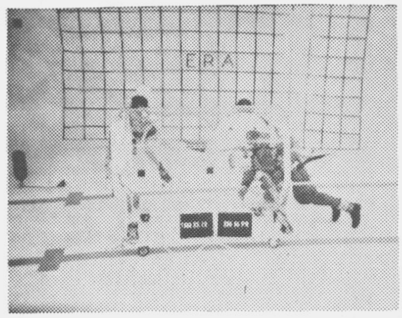
°Average of three consecutive runs of Subject A

NR-not required

These values show the same trend as the normal ingress-egress maneuver.



Open Door



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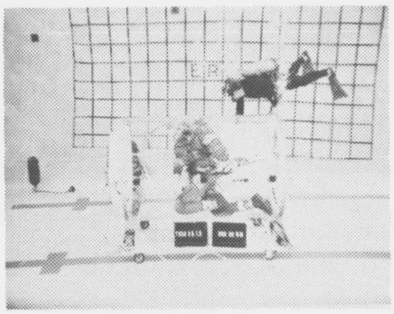
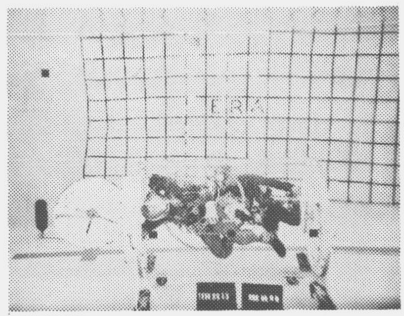


Turnaround



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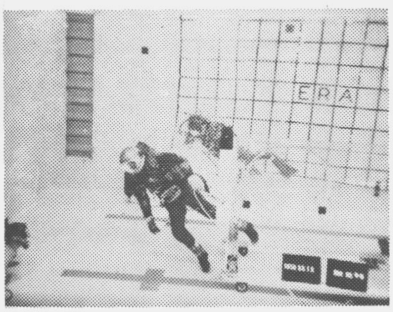
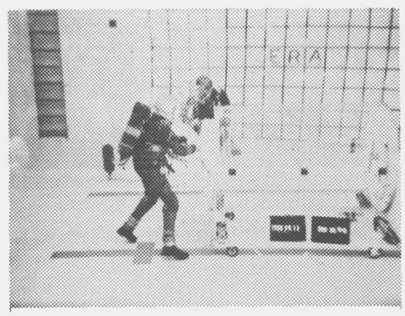
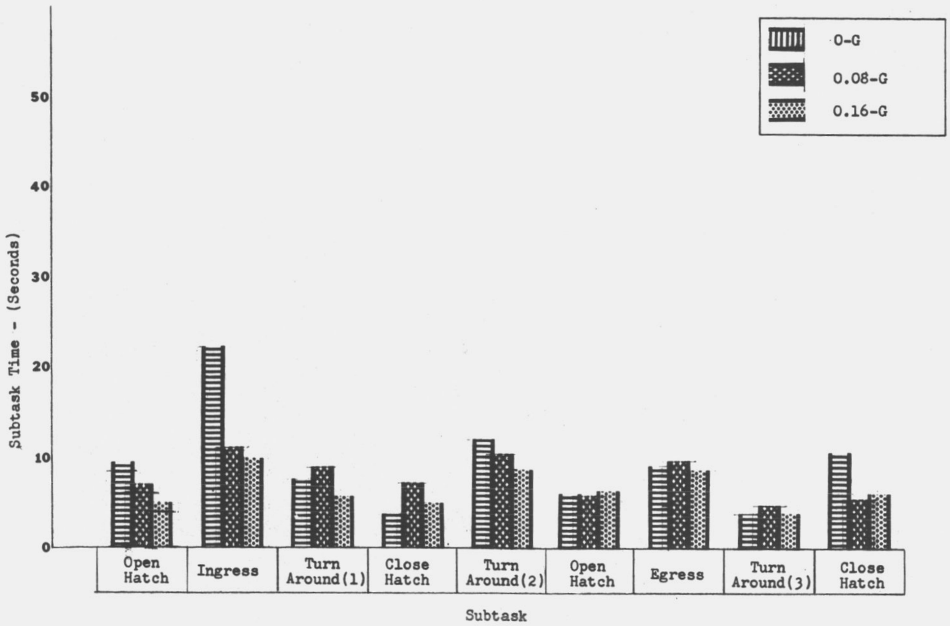


Exit



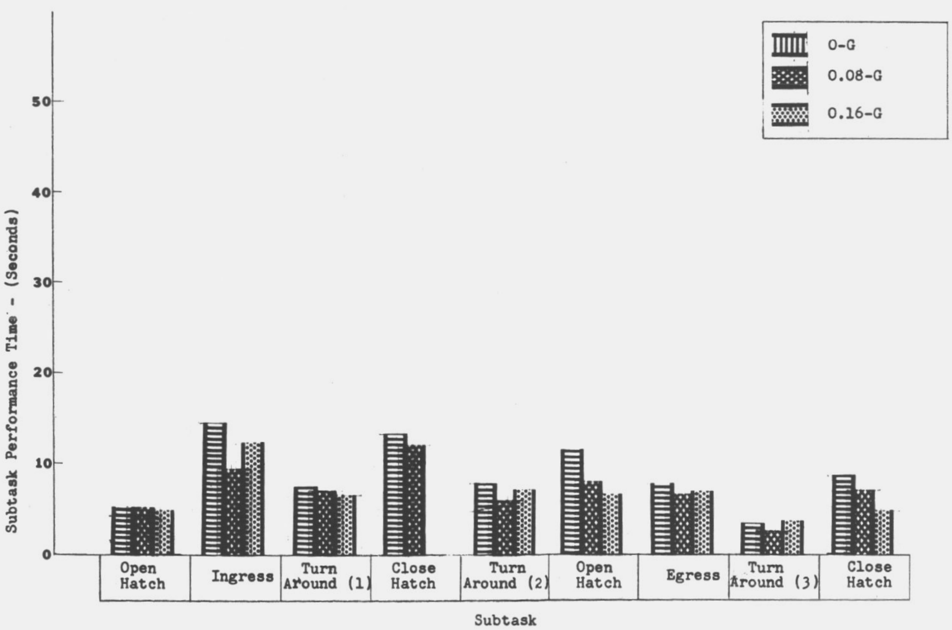
Close Door

4.2-48 Sequence Of Normal Ingress-Egress Maneuver - Task 13



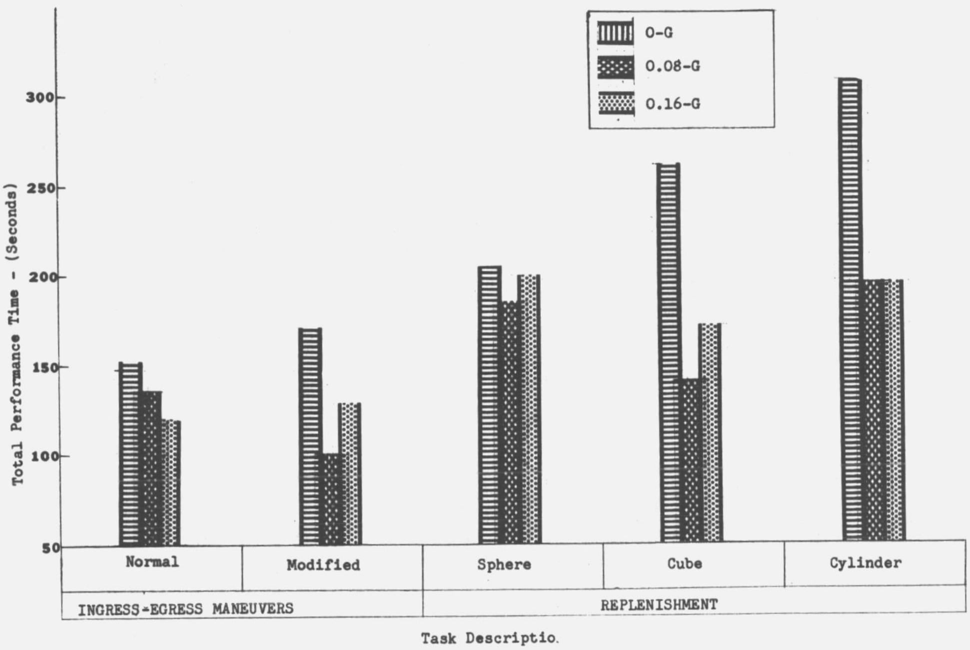
The Effect of Gravity Level Variation on Subtask Performance Time Direction O-C Subject A

Figure 4.2-49



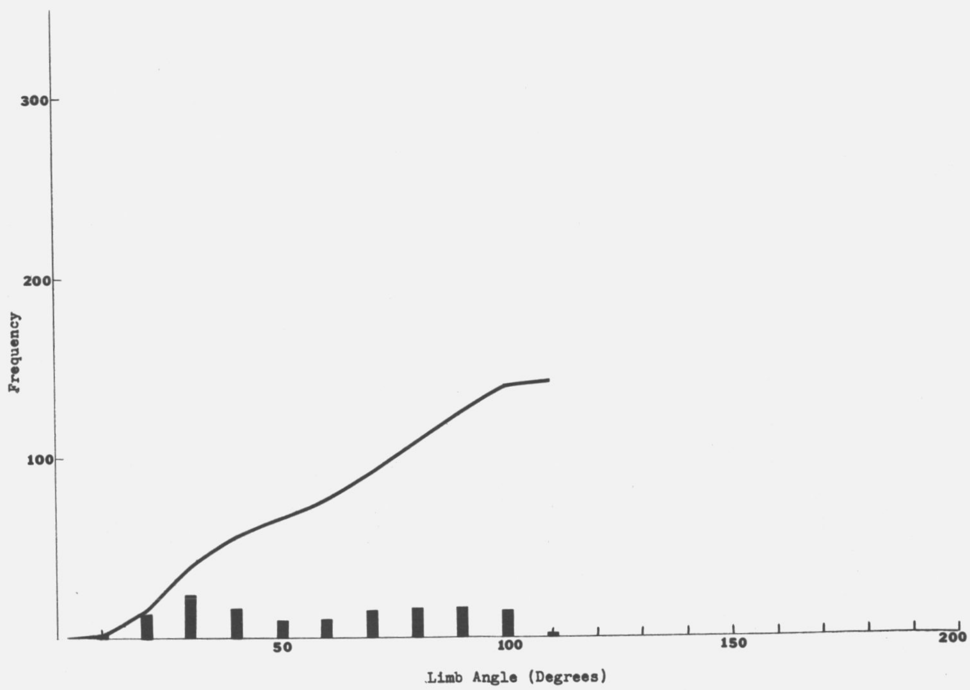
The Effect of Gravity Level Variation on Subtask Performance Time Subject A Direction C-O

Figure 4.2-50



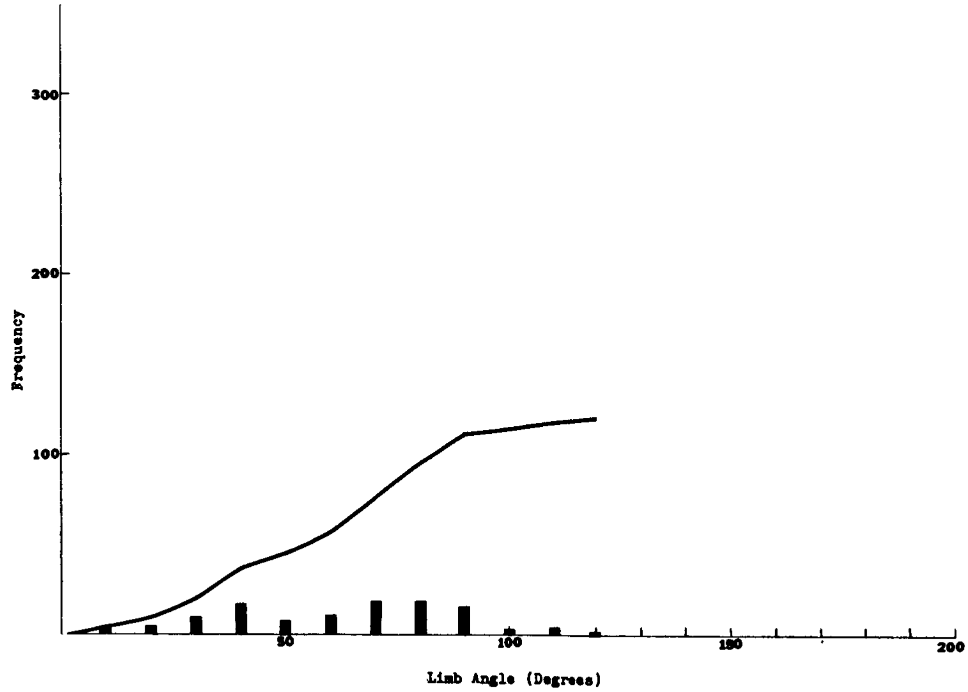
The Effect of Gravity Level Variation on Total Performance Times For Ingress-Egress and Replenishment Maneuvers

Figure 4.2-51



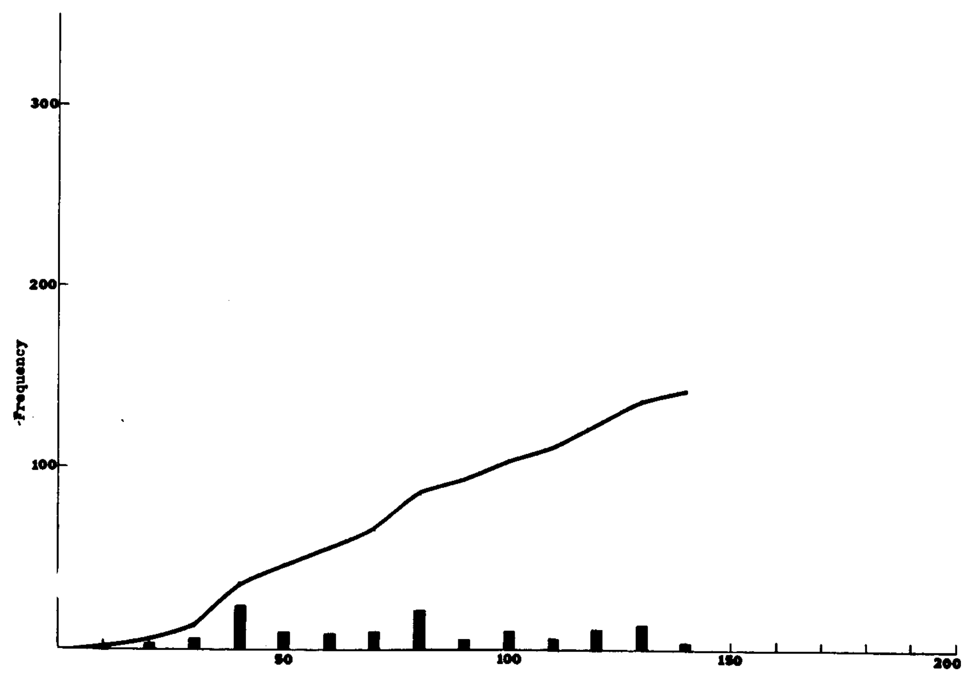
Limb Angle Frequency Profile - Elbow Angle - Subject A - Task 13/Run 4

Figure 4.2-52



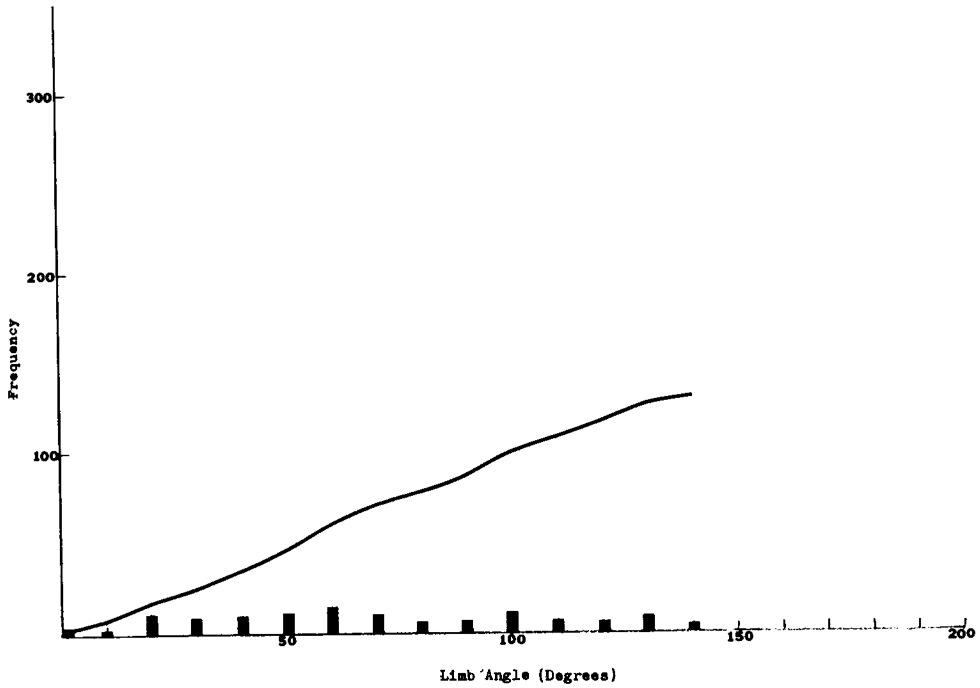
Limb Angle Frequency Profile - Elbow Angle - Subject A - Task 13/Run 3

Figure 4.2-53



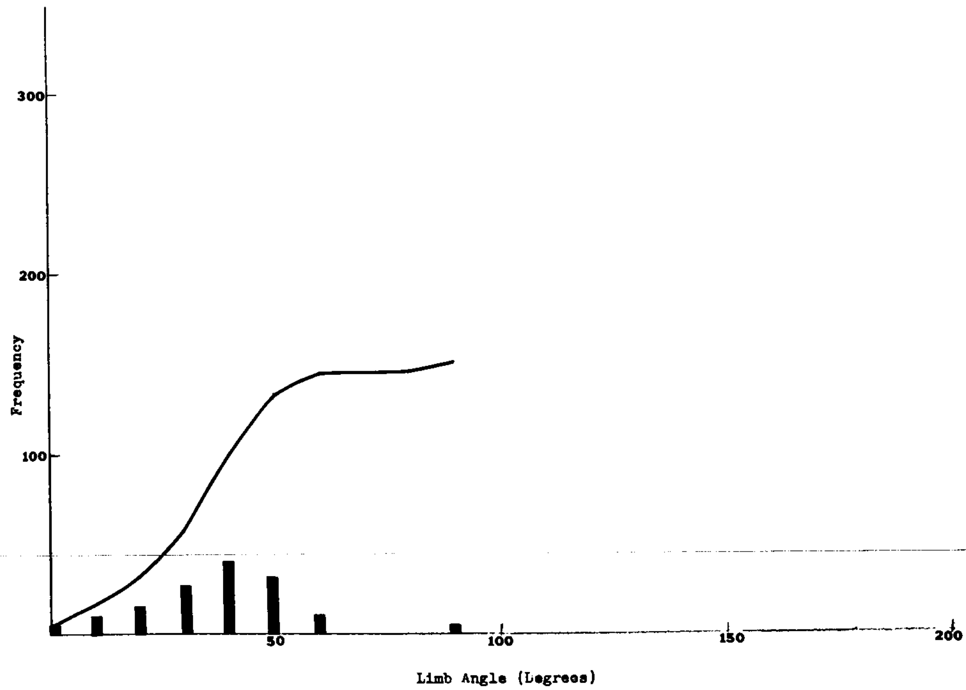
Limb Angle Frequency Profile - Knee Angle - Subject A - Task 13/Run 4

Figure 4.2-54



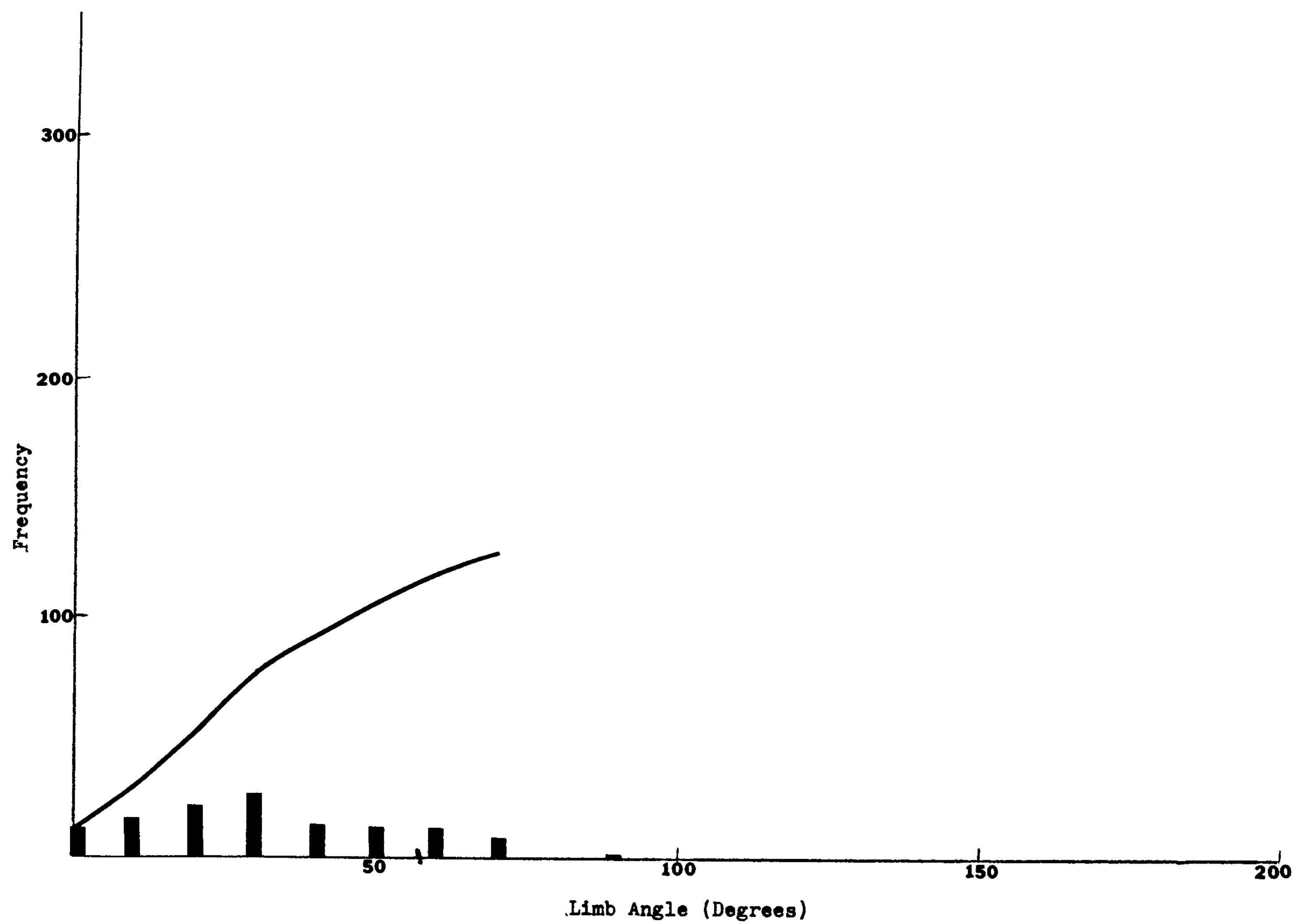
Limb Angle Frequency Profile - Knee Angle - Subject A - Task 13/Run 3

Figure 4.2-55



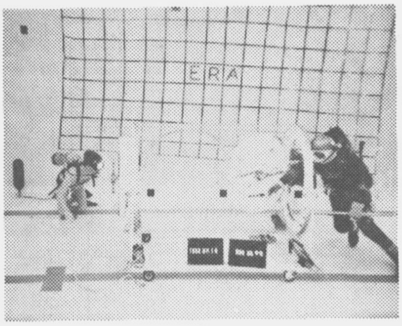
Limb Angle Frequency Profile - Hip Angle - Subject A - Task 13/Run 4

Figure 4.2-56

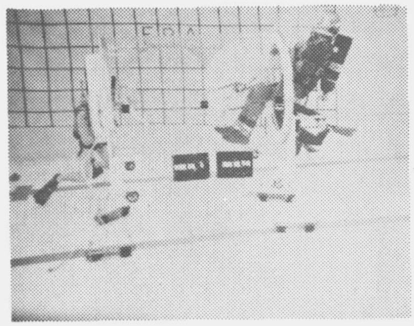


Limb Angle Frequency Profile - Hip Angle - Subject A - Task 13/Run 3

Figure 4.2-57



Open Door



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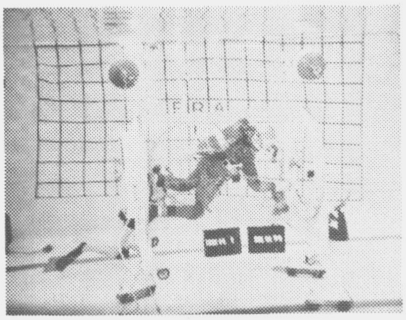
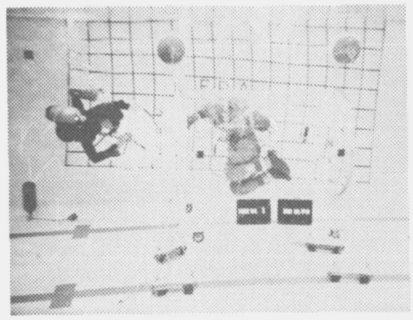
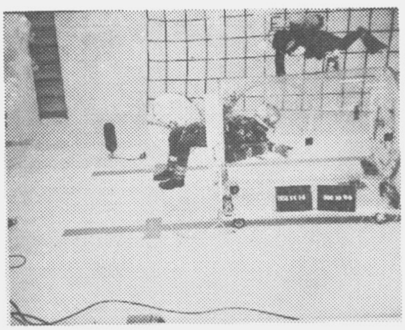


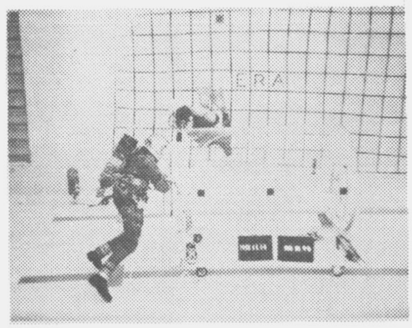
Close Door



Turnaround

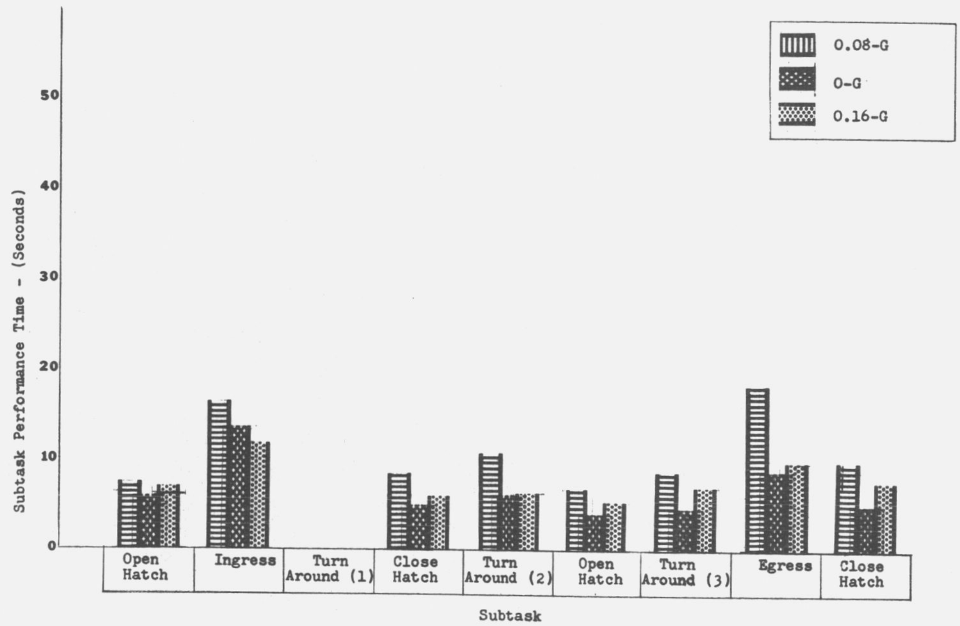


Exit



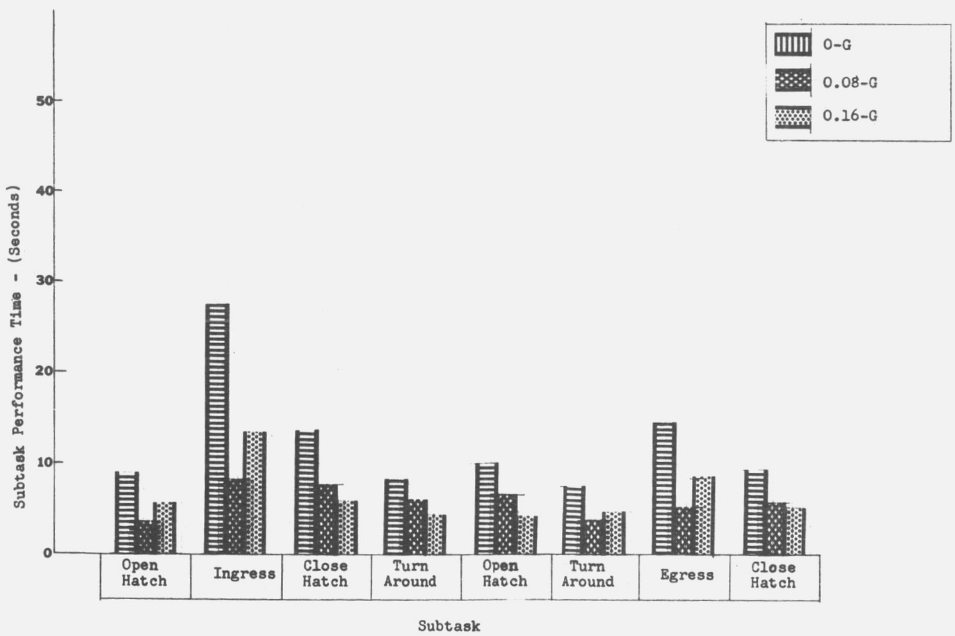
Close Door

4.2-58 Modified Ingress-Egress Sequence - Task 14



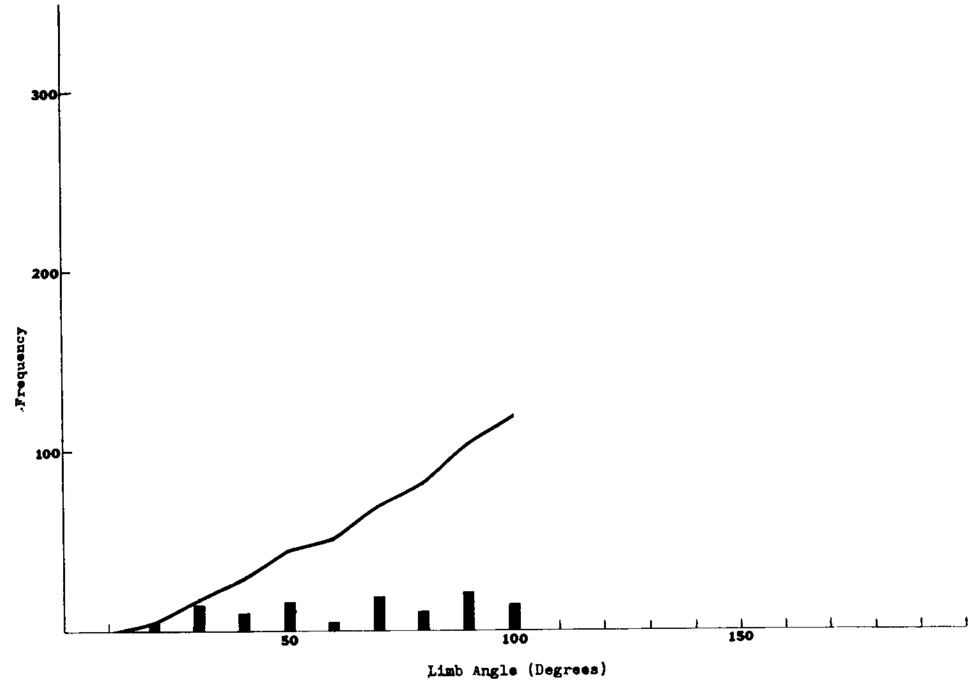
The Effect of Gravity Level Variation on Subtask Performance Time Subject A Direction O-C

Figure 4.2-59



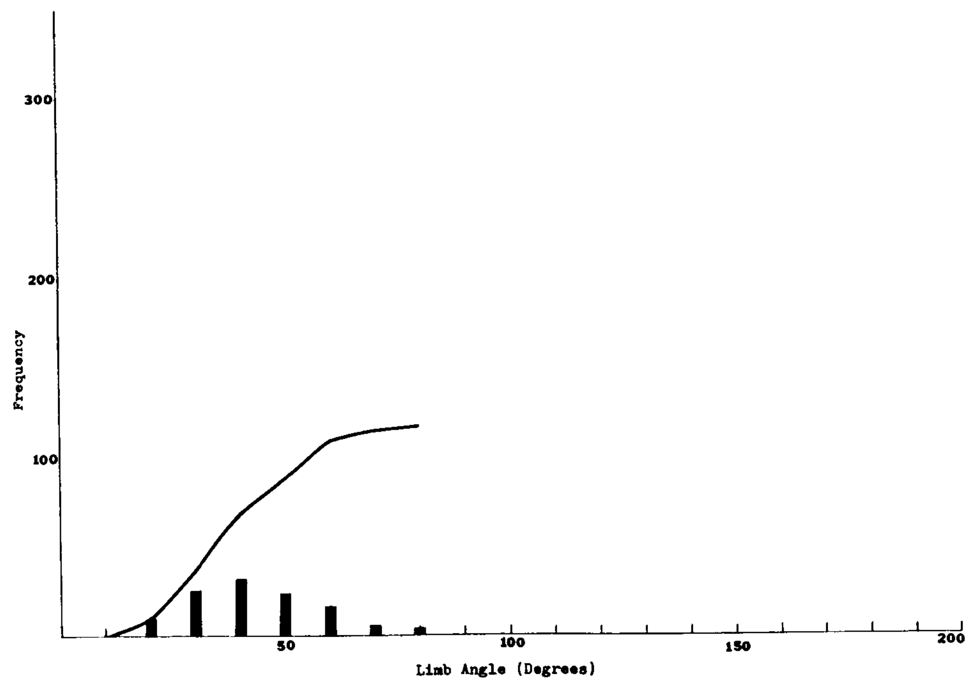
The Effect of Gravity Level Variation on Subtask Performance Time Subject A Direction C-O

Figure 4.2-60



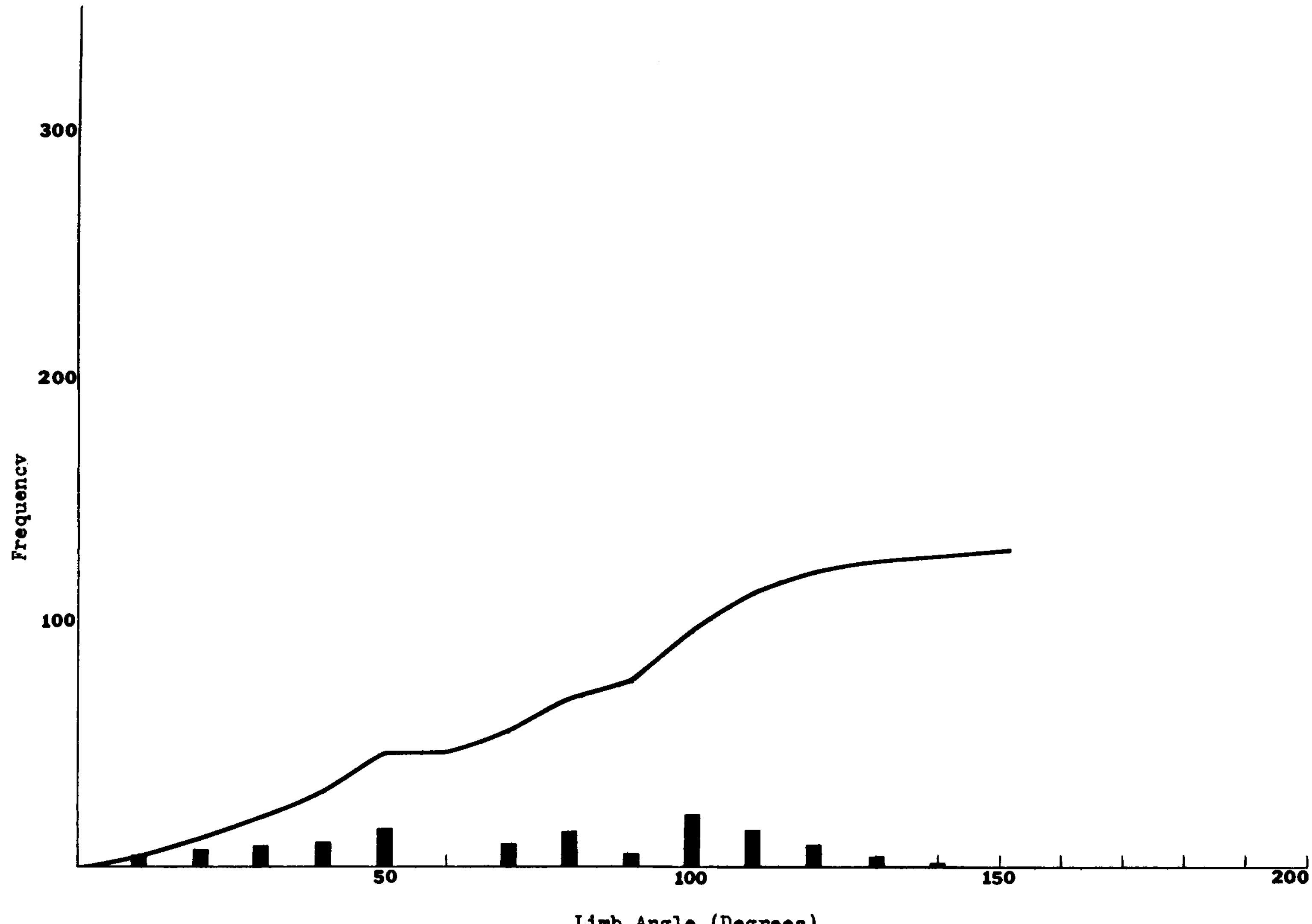
Limb Angle Frequency Profile - Elbow Angle - Subject A - Task 14/Run 2

Figure 4.2-61



Limb Angle Frequency Profile - Hip Angle - Subject A - Task 14/Run 2

Figure 4.2-62



Limb Angle Frequency Profile - Knee Angle - Subject A - Task 14/Run 2

Figure 4.2-63

4.2.8 INGRESS-EGRESS THROUGH VARIOUS GEOMETRY AIRLOCKS

4.2.8.1 OBJECTIVES

The majority of tasks performed during this contractural phase utilized cylindrical geometry airlock structures and the data derived during this study utilized this as a baseline. The design of airlock structures for future missions, however, will not always be centered around cylindrical geometry structures. Some designs will utilize spherical configurations in order to optimize the volume to surface ratio and to make those appropriate space utilization in the parent spacecraft. Such a configuration was originally conceived for use in the LRC-MORL study. This configuration, described in section 4.2.2 was used to provide comparative "first-order" information to determine the relationship of the ingress-egress task performance to various other geometries.

A further investigation on ingress-egress relative to a capsule configuration was also performed. The details of the capsule configuration are also given in section 4.2.2. The objectives of this demonstration was to visually investigate the procedures and problems encountered while maneuvering through spherical and capsule geometry structure.

4.2.8.2 INGRESS-EGRESS FROM A SPHERICAL GEOMETRY-TASK 19

4.2.8.2.1 DISCUSSION

The task started with the subject holding the entry bar with his left hand while opening the hatch (1) with his right hand. He entered the spherical structure in a head-first manner, turned around inside, closed the hatch and turned around a second time. The subject, oriented toward the opposite hatch, pushed off with his feet and drifted (with slow forward velocity) toward the opposite hatch (2). After grasping the hatch handle, he opened the hatch and made a head-first egress using the tether line attached to the hand-rail to pull himself back to the structure for subsequent hatch (2) closure.

The subject started the return passage by pushing away from the structure, and turning by pulling on the tether in a hand over hand fashion. He opened the hatch, entered in a head first manner and turned around internal to the spherical structure employing the tether as a motion aid. After he approached the hatch a second time, he pushed the tether line outside and closed the door with his right hand, and after some minor difficulty in reaching the opposite door, opened it and made a head first exit, using the exit bar to steady himself while exiting, turnaround and closing the hatch.

The next run was made using a feet first entry and exit procedure similar to Task 2. The subject made use of the external handrail to maneuver around in order to close the hatch.

4.2.8.2.2 RESULTS

The subject was able to perform the ingress-egress maneuver with little apparent difficulty in both the normal and modified mode. On one occasion, he had difficulty in making the transit to the opposite door. This was caused by the drag of the water which in turn caused him to momentarily lose contact with the sides of the airlock. Figure 4.2-64 is a pictorial sequence of the head-first (normal mode) and feet-first (Modified) of the ingress-egress maneuver. Because of the smooth walls and the size of the airlock, the subject, for the normal ingress-egress found that his turnaround within the airlock was made easier when he brought the tether inside and used it as a turning aid. This decreased the turnaround time by 36%.

The results of this task demonstrated the feasibility of using a 7 foot spherical airlock while performing ingress-egress maneuvers. Since this task was principally one of a demonstration nature, no detailed analysis was performed.

The total time required to execute the normal ingress-egress task was 255.8 seconds. The modified ingress-egress maneuver required only 171.9 seconds. This is 44% of the time required to perform the normal ingress-egress task. This difference was due mainly to the size of the airlock. For the normal ingress-egress maneuver, the subject was not able to press against the walls and pull himself inside as in the cylindri-airlocks. Once inside, he had to make a turnaround. This was very difficult because the airlock did not have internal motion aids. However, this was not the case during the modified ingress-egress maneuver. The subject was able to hold onto the edge of the door opening until the entry was complete. Once inside he was able to augment the turnaround by holding onto the door handle. This accounted for the large difference in performance times between the two tasks.

4.2.8.3 INGRESS-EGRESS FROM A CAPSULE GEOMETRY HATCH-TASK 20

4.2.8.3.1 PERFORMANCE

4.2.8.3.1.1 PROCEDURES

The capsule configuration described in section 4.2.2 was used to investigate the procedures and problems of ingress-egress through a hatch into a capsule configuration vehicle. For this task a version of the current Gemini vehicle was employed because of its availability and because it represented current vehicle state-of-the-art. The subject, wearing the pressurized Mark IV-Mod 0 FPS (3.5 PSIG) was required to ingress-egress the capsule in a head first and feet first manner, but was not required to effect hatch closure due to the internal construction of the mock-up. Test runs of ingress-egress were performed in conjunction with Task 21. As a result both tasks employed the same configuration; capsule configuration connection to the spherical airlock configuration by a safety tether line.

4.2.8.3.1.2 INGRESS-RUN 1

Elapsed Time: 0.0 Seconds

The task began with the subject positioned outside the capsule while holding the tether with both hands and the longitudinal axis of his body perpendicular to the tether line. Relaxing his grip on the tether with his right hand, the subject turned to face the capsule. The subject simultaneously placed both feet through the hatch opening to initiate the entry. Turning slightly to his left, he grasped the tether with both hands to pull himself further inside the capsule. Assuming a slightly crouched position, the subject grasped the left and right side of the hatch opening to pull himself into the capsule to complete the ingress maneuver.

Elapsed Time: 21.8 Seconds

4.2.8.3.1.3 EGRESS-RUN 1

Elapsed Time: 0.0 Seconds

This maneuver began with the subject positioned in a slightly crouched position within the capsule. Turning slightly to his left, he grasped the tether line with both hands and pulled himself free of the capsule.

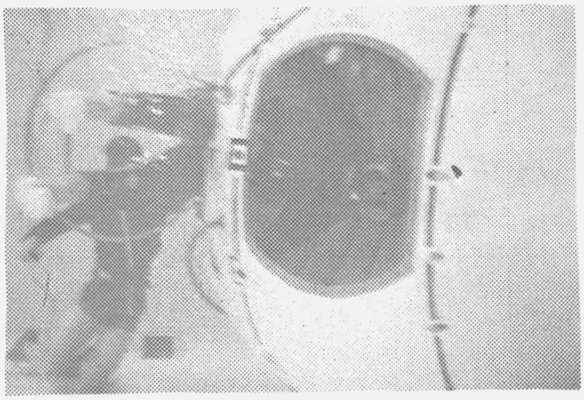
Elapsed Time: 6.2 Seconds

Figure 4.2-65 shows the subject performing ingress and egress with the capsule mockup.

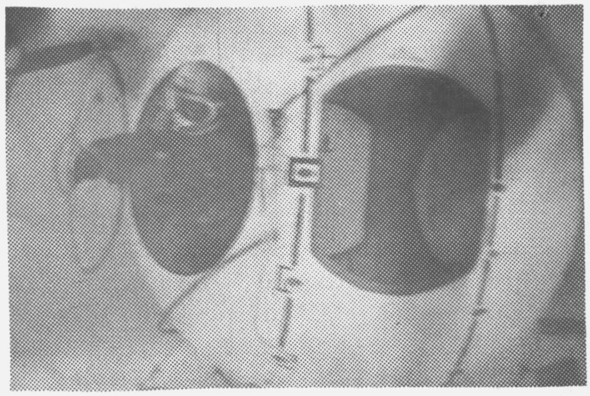
4.2.8.3.2 RESULTS

The ingress-egress maneuvers to a capsule configuration employed the feet-first (modified) entry and head-first (normal) exit. Volume restrictions imposed by the capsule configuration did not allow head-first entry or feet-first exit. These volume restrictions, in addition to the problems imposed by framework on the inside of the capsule, produced many safety problems and caused deviations from original test procedures.

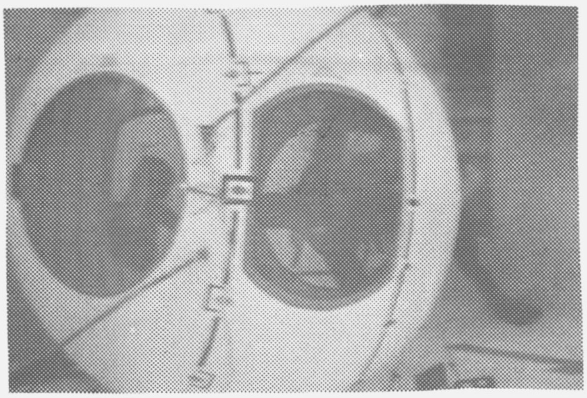
As furnished by the Government, the capsule hatch and interior framework had many sharp edges and protrusions. During the test operations these sharp edges produced numerous suit punctures. As a result the capsule was modified to eliminate the sharp edges and corners. Because of the possibility of entanglement in the interior framework no attempts were made to completely ingress the capsule or attempt to close the hatch.



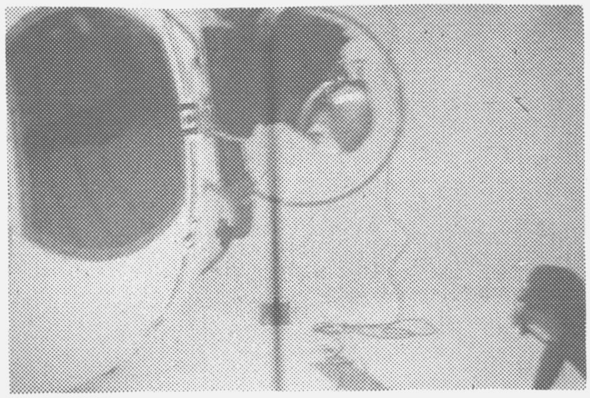
Ingress



Close Door

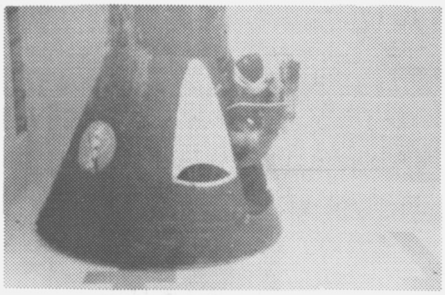
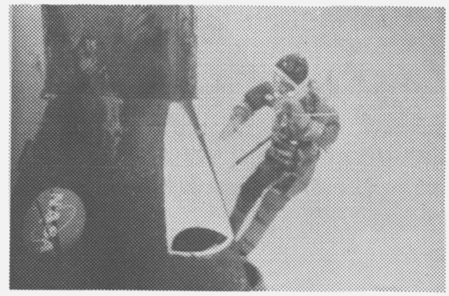


Open Door

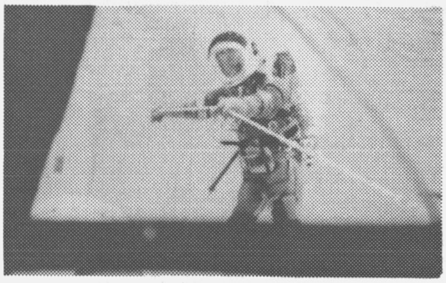
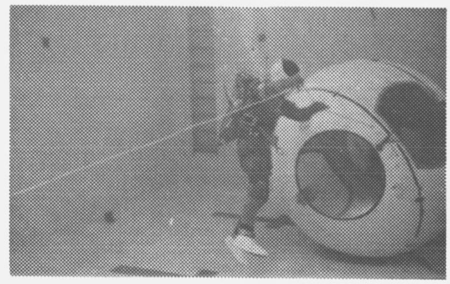


Exit

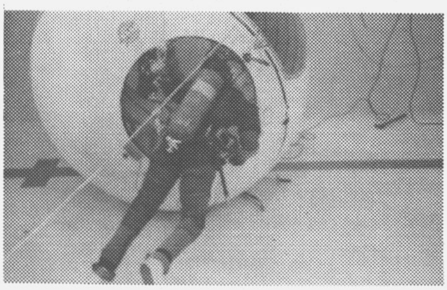
4.2-64 Sequence Of Ingress-Egress Maneuvers For A Spherical Airlock Geometry

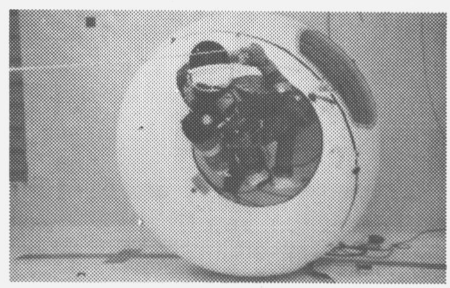
Egress Capsule

Transfer To Spherical Airlock

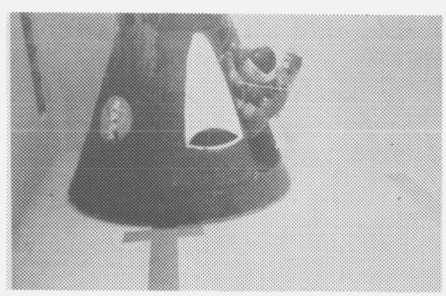


Ingress Spherical Airlock



Egress Spherical Airlock

Transfer To Capsule



Ingress Capsule

4.2-65 Sequence Of Ingress-Egress Maneuvers For A Capsule Airlock Geometry

4.2.9 CONCLUSIONS

Study results show that ingress-egress maneuvers may be performed in cylindrical airlocks of 42 inch diameter and larger. The results indicate that the ingress-egress maneuver should not exceed the limits set forth in Table XIV in Figure 4.2-66.

TABLE XIV

SUGGESTED MINIMUM TURNAROUND LENGTHS FOR VARIOUS DIAMETER AIRLOCK

Airlock Diameter -Inches	Suggested Minimum Length for Successful Turnaround While Pressurized-Inches
42	≥ 48
48	≥ 36
60	≥ 36

Hatch diameter greatly affected ingress-egress maneuvers. Figure 4.2-66 shows the relationship of airlock diameter to ingress time. It can be seen that ingress time is nearly independent of hatch diameter for hatches with diameters smaller than the airlock diameter. When hatch sizes equalled or exceeded the airlock diameters, ingress times increased.

Hatch size also affected the minimum lengths in which the ingress-egress maneuver could be completed. This was witnessed in the subject's attempts to negotiate ingress-egress in the 60 inch diameter airlock with a length of 24 inches. Although the subject was able to ingress and turnaround the combination of a 32 inch diameter hatch and 60 inch diameter airlock with a length of 24 inches, the airlock did not permit egress. In all probability, the maneuver could have been completed with a larger hatch.

Analysis of performance involving airlock dimensional variation permitted an extrapolation of data regarding minimum length to turnaround indicated that the time required to turnaround is independent of the length of the airlock for airlock sizes where turnaround is feasible. This result is depicted in Figure 4.2-27. It should also be noted that there is an apparent exponential relationship between airlock diameter and the time per turnaround.

Data recorded for the normal and modified ingress-egress maneuvers does not indicate which mode is the optimum. The optimum performance mode appears to be a composite of these two maneuvers; a feet first ingress and head first egress. A maneuver of this type allows the subject to make maximum use of the prepositioning ability of his hands.

During this study, the 48 inch diameter airlock was equipped with external motion aids; a rigid exit bar and flexible tether line. There was no attempt to vary these aids during the tests but it became quite evident that these two aids while not optimized, do enhance ingress-egress to a degree. They provide necessary prepositioning ability to the subject. The exit bar proved to be the more universally useful of the two aids. Ingress-egress times were less for the use of the exit bar than for the tether line.

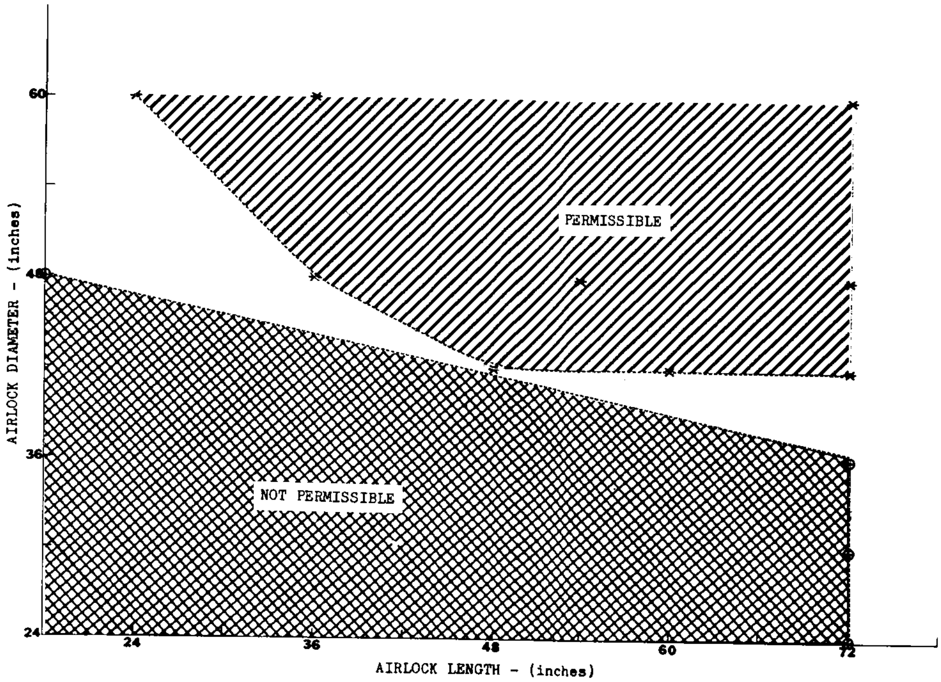
During the performance of the reduced gravity tests, a rigid support was definitely needed during egress. Because of his positive weight, the subject had a tendency to fall from the airlock. He made use of the rigid supports available, i.e. doors, door latches, exit bar, but found the flexible tether inadequate for this purpose.

In addition to external motion aids, the tests also indicated the need for internal traction aids. In the larger diameter airlocks of 60" and 48", the internal handhold received only nominal use. However, in the 42 inch diameter airlock, the subject found it very difficult to execute a turnaround without the use of a traction aid. In the 72 inch length this aid was supplied by the latch handles of the doors. In the shorter length airlock the end panel and bulkhead were used by the subject to enhance the turnaround.

This need for handholds was also apparent in the reduced lengths of the 60 inch diameter airlock. When the length of the airlock was reduced to a 24 inch, the ingress-egress maneuver could have been completed if either the hatch size was increased or a handhold had been judiciously placed inside the airlock.

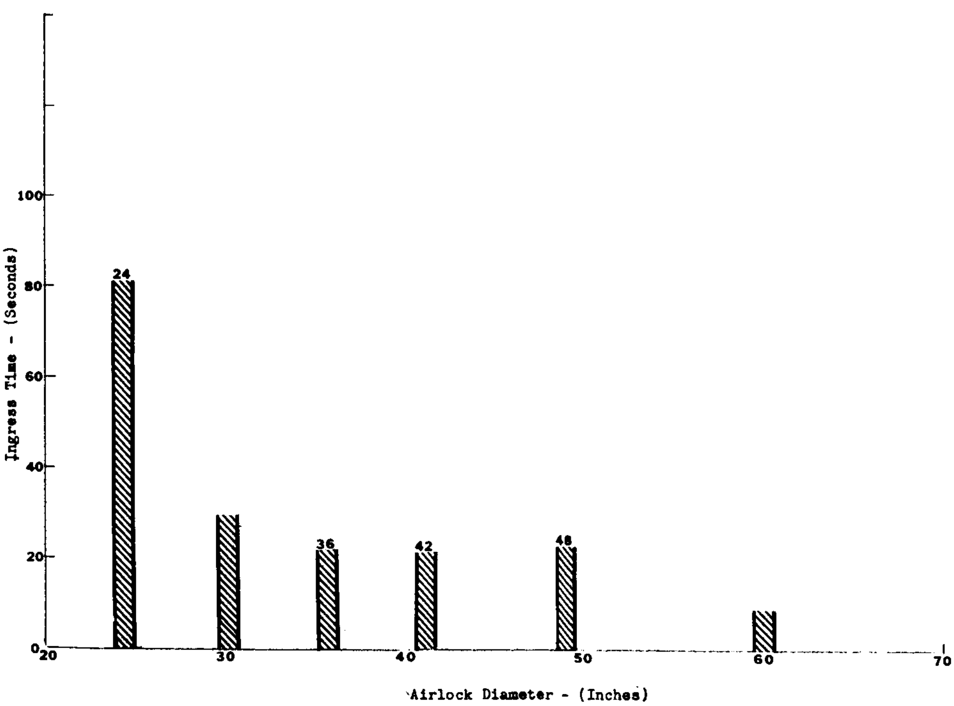
Data indicates that a reduced gravity levels, ingress-egress maneuvers required less time for performance at the 0.08G level than the neutrally buoyant or 0.16 G level. This shows that there may be a partial gravity level between OG and 1G at which ingress-egress performance is most efficient.

Tests performed to demonstrate the feasibility of ingress-egress maneuvers in a spherical airlock configuration and capsule-hatch configuration showed that these maneuvers were feasible but optimum performance dictates consideration of internal and external motion-traction aids.



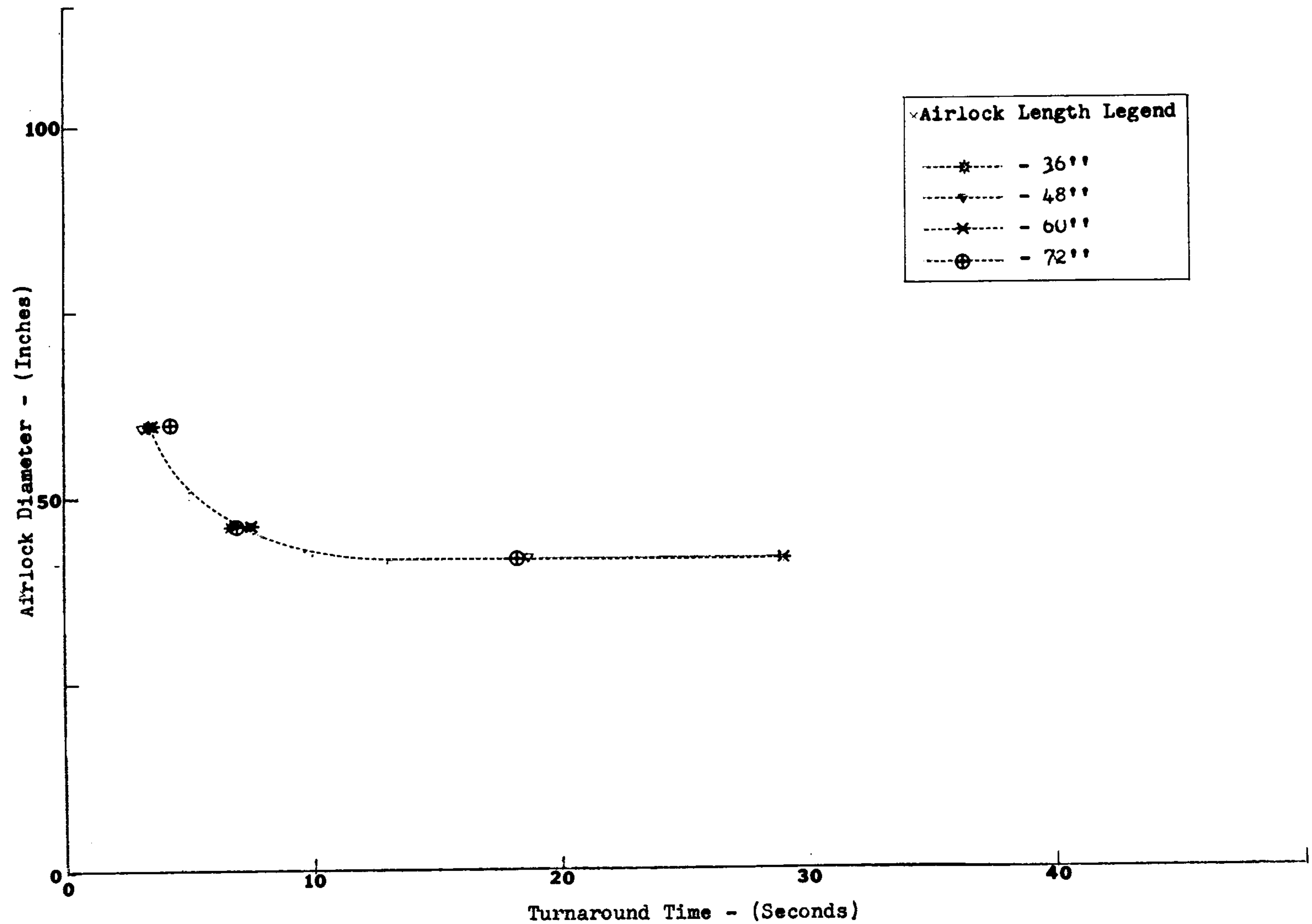
Envelope of Permissable Turnaround Region for Various Dimension Airlocks - Simulated Zero Gravity

Figure 4.2-66



The Effect of Airlock Diameter Variation on Ingress Time - 72'' Length Airlock

Figure 4.2-67



The Effect of Airlock Dimensional Variation on Turnaround Time For Simulated 0-G Subject A

Figure 4.2-68

4.3 RESCUE

4.3.1 OBJECTIVES

One of the most critical functions to be performed by pressure-suited astronauts relating to airlocks, is that of rescue. Rescue in the sense investigated during this contractural phase constituted the retrieval of an astronaut (pressurized at 3.5 PSIG) existing in an immobilized state, in close proximity to the airlocks by another pressurized astronaut either internal to or external to the airlock structure. The objectives of these demonstrations was to investigate the feasibility of transferring disabled astronauts into the airlock. Subject analysis was limited to measurements of total task time and visual interpretation of the performance characteristics. Limb angle profile analysis was not compatible with these tasks because of performance inconsistency between test runs and the visual obscuration due to two subject operation.

The rescue demonstration began with the immobilized subject balanced to either neutral buoyancy or simulated 0.08, 0.16 G_e and located outside the circular hatch of the 48" diameter 6' length cylindrical airlock. The subject was tethered to the airlock structure by a 0.75" diameter nylon rope, 8' length. Test variations included the rescuer inside the airlock, pulling the immobilized subject into the airlock and the rescuer outside the airlock, pushing the immobilized subject into the airlock. When the immobilized subject was totally within the airlock structure the rescuer entered or remained internal to the airlock and attempted to close the circular hatch, thus completing the cycle.

4.3.2 EQUIPMENT DESCRIPTION

To assess the operational characteristics of the rescue maneuver, the 48" diameter cylindrical airlock as described in Section 4.1 was used. The tests were originally designed to employ an unmanned water filled suit at 3.5 PSIG to simulate the disabled astronaut. However, during test preparations, it was observed that the water-filled suit did not exhibit the rigidity common to that of a pressure suited man. Consequently, two subjects were balanced to the desired gravity level. One subject was instructed to maintain a relaxed immobilized position while the other subject performed the rescue maneuver.

4.3.3 SIMULATED ZERO-GRAVITY RESCUE-TASK 6

4.3.3.1 PERFORMANCE ANALYSIS-RUN 7

Elapsed Time: 0.0 Seconds

This maneuver was initiated with the rescuer inside the airlock facing the oval door and the rescuee attached to the extended tether line on the outside of the airlock. A sequence of pertinent maneuvers is shown in Figure 4.3-1.

Remaining inside the airlock, the rescuer grasped the tether line and pulled the rescuee towards the airlock. As the rescuee approached the airlock, the rescuer grabbed the rescuee's helmet and pulled him into the airlock head-first facing down.

Elapsed Time: 76.8 Seconds

Once ingress was completed the rescuer began moving towards the oval door. While reaching for the door, his relief valve snagged and was pulled from his suit, causing the loss of pressure.

Emergency procedures were initiated at this point to insure the safety of the subject. Once repairs were made, testing began again at the cessation point. This time the rescuer was able to reach the oval door without mishap. The rescuer closed the door after he had pushed the rescuee's feet aside.

Elapsed Time: 87.0 Seconds

The rescuer turned around to face the circular door. The rescuer then attempted to exit but was prevented from doing so by the rescuee's head which was partially blocking the hatchway. Retreating from the hatchway, he pushed the rescuee away from the opening towards the oval door and then proceeded to make his exit.

Elapsed Time: 167.0 Seconds

The rescuer was able to close the door and end the test after pulling the rescuee clear of the door.

Elapsed Time: 211.7 Seconds-End of Maneuver

4.3.3.2 RESULTS

The results of the rescue operation are illustrated in Table XV which compares the two modes of operation: (mode 1) placement of the rescuee into the airlock by a rescuer external to the airlock, (mode 2) placement of the rescuee into the airlock by a rescuer positioned internal to the airlock.

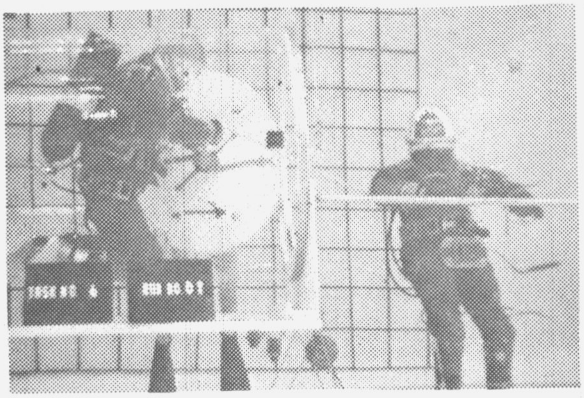
Subject de-briefing and time-motion analysis indicate that (mode 2) is more efficient than (mode 1) in this type of rescue operation. For (mode 1) the subjects expressed a feeling of inadequacy while trying to push the rescuee into the airlock. However, for (mode 2) it was found that the airlock wall provided needed traction and positioning to pull the rescuee into the airlock. (Mode 2) resulted in minimum time to bring the rescuee into the airlock and close the door.

Tests were continued past the end point designated in (mode 2) to determine the feasibility of turnaround of the rescuer inside the airlock as regards the spatial limitations. It was found that the turnaround and exit from the opposite end of the airlock was feasible; however, a serious problem arose during the investigation. During two attempts to turnaround, the subject had his relief valve snag on the rescuee and pulled from his suit.

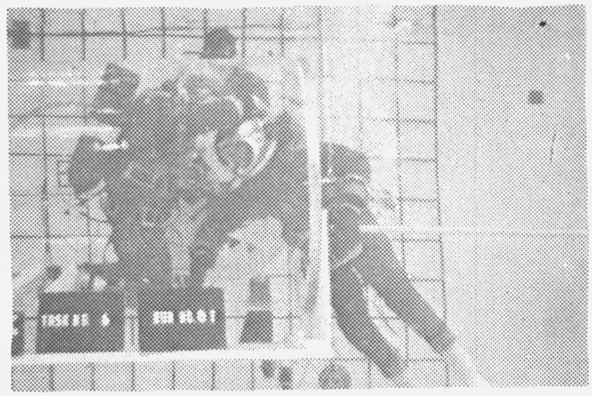
TABLE XV

COMPARISON OF RESCUE MODES-SIMULATED ZERO GRAVITY

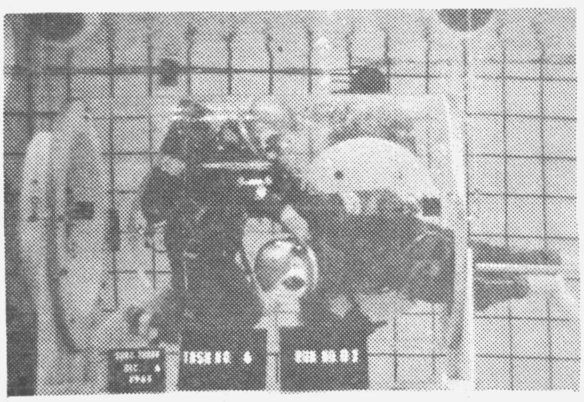
Task Description	Time - to complete - Seconds	
	Mode (1)	Mode (2)
Rescuer opens oval hatch and egress-to vicinity of immobilized subject.	18.4	7.5
Rescuer maneuvers immobilized subject to airlock hatch preparatory to ingress-transference	28.5	46.4
Rescuer places immobilized subject into airlock and closes hatch	170.7	47.3
Total Time	217.6	101.2



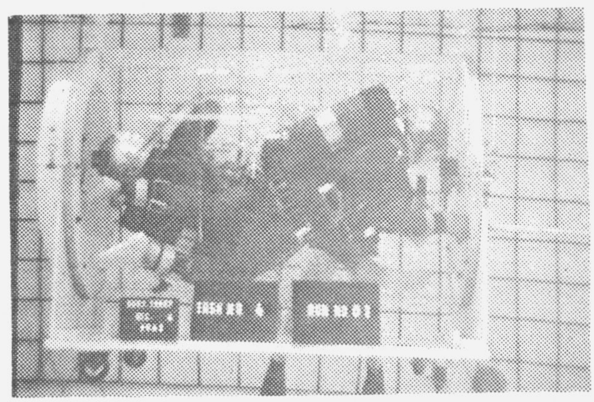
Rescuer Opens
Airlock Door



Rescuer Maneuvers Immobilized
Subject to the Airlock



Rescuer Maneuvers
Immobilized Subject Into
The Airlock



Rescuer Turns Around
And Closes Airlock Door

4.3-1 Sequence Of Zero Gravity Rescue

4.3.4 SIMULATED REDUCED GRAVITY RESCUE-TASK 18

4.3.4.1 PERFORMANCE ANALYSIS

4.3.4.1.1 - 0.16 GRAVITY-RUN 1

Elapsed Time: 0.0 Seconds

This test began with the rescuee lying on the pool bottom and secured to the airlock by a tether line. The rescuer was positioned inside the airlock with both doors closed. The rescuer grasped the tether line and pulled the rescuee towards the airlock. When the rescuee reached the airlock, the rescuer attempted to pull him inside the airlock. After several unsuccessful attempts to pull the rescuee into the airlock, the rescuer exited the airlock in order to push the rescuee into it.

Elapsed Time: 44.4 Seconds

A second test was performed in which the rescuer exited the airlock and pulled the rescuee to the airlock. When both subjects reached the door, the rescuer lifted the rescuee's feet and placed them through the oval door hatchway. He then lifted the rescuee by the shoulders and pushed him into the airlock. The rescuer was then able to push the rescuee to one side and make his entrance. He experienced considerable difficulty trying to negotiate the rescuee's head and shoulders but was able to execute a turnaround near the circular door where the rescuee's leg allows more space for the maneuver. It soon became apparent that the rescuer could not close the oval door after the turnaround and the test was halted. A sequence of pertinent maneuvers is shown in Figure 4.3-2.

Elapsed Time: 187.0 Seconds-End of Maneuver

4.3.4.1.2 - 0.08 GRAVITY-RUN 2

Elapsed Time: 0.0 Seconds

This test began with both subjects on the exterior of the airlock. The entry of both subjects was similar to that used in the 0.16 gravity situation. The rescuer struck or snagged the on-off button of his helmet regulator in the attempt to turnaround. This caused the subject's air supply to be cut off, simultaneously deflating the helmet faceplate seal.

4.3.4.2 RESULTS

The results of the rescue operation are listed in Table XVI. This table shows the subtask times as determined from the time/motion analysis.

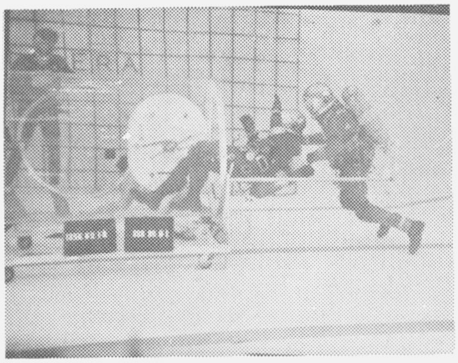
TABLE XVI

THE EFFECT OF GRAVITY LEVEL VARIATION ON RESCUE OPERATIONS-MODE (1)

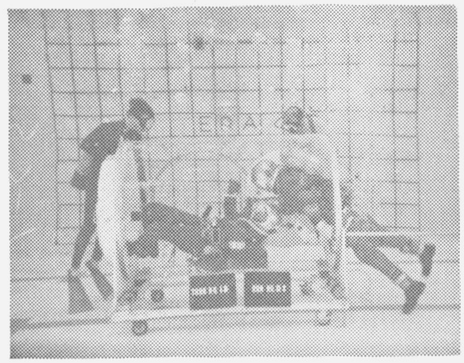
Subtask Description	Gravity Level $0.08G_e$	Gravity Level $0.16G_e$
a. Rescuer exits airlock	not performed due to equipment interactions	11.6
b. Rescuer maneuvers rescuee to airlock and places him inside-transferance	96.8	65.3
c. Internal turnaround	cessation of task due to equipment interaction	22.8
d. Rescuer closes hatch	cessation of task due to equipment interaction	cessation of task due to equipment interaction

The rescue task performance for Task 18 incorporated the same modes as discussed in Task 6. However, it was found that, at the reduced gravity levels, the subject could not pull the rescuee into the airlock with him. This was due to the weight of the two subjects. The rescuer found that he could no longer get the rescuee up over the edge of the hatchway. Therefore rescue mode (2) was not performed. Consequently, the tests were performed at both gravity levels with the subject placing the rescuee into the airlock from the outside.

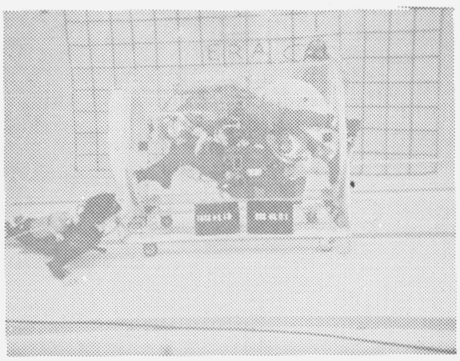
The times required for the task performance of rescue Mode (1) are shown in Table XVI. It can be seen by comparing these results with simulated zero gravity rescue of Task 6 that the increased weight causes an increase in the subtask performance time.



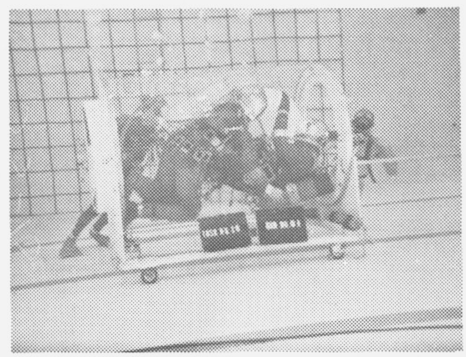
Rescuer Places Immobilized



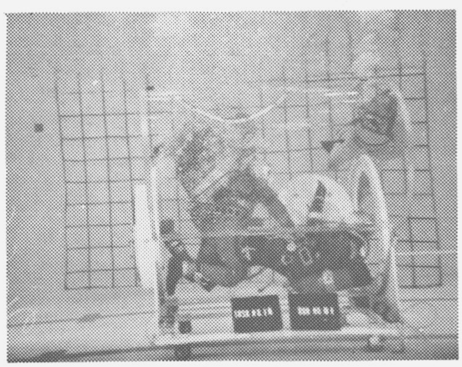
Rescuer Enters Airlock



Rescuer Completes Entry



Rescuer Turnsaround



Suit Failure - Emergency Procedures Initiated

4.3-2 Sequence Of Simulated Partial Gravity Rescue

4.3.5 CONCLUSIONS

Although the investigations into the area of rescue were of a superficial nature, many of the performance characteristics were very noticeable. The following characteristics presented themselves:

- Need for external and internal traction aids.
- Dependence of rescuer position relative to the airlock and simulated gravity level.
- Injection of added safety precautions for both subject and disabled astronaut.

The need for external traction aids was apparent for those test runs in which the subject, stationed outside the airlock, was required to push the immobilized subject into the airlock. Being in a tractionless state, the subject had great difficulty maintaining his position while pushing the immobilized subject into the airlock.

In all simulated zero gravity tests, the rescue maneuver was performed in less time when the subject was positioned internal to the airlock and pulled the immobilized subject into it. This mode of operation allowed the subject to compensate for tractionlessness by pushing against the airlock walls and end panels.

When the simulated gravity level was increased from 0G to 0.08G and 0.16G, the subject was no longer able to lift the immobilized subject over the hatch sill and pull him into the airlock. Consequently, the reduced gravity tests were performed with the subject pushing the immobilized subject into the airlock.

While the use of two subjects weighted to neutral buoyancy in itself increased the safety hazards involved in the task performance, attempts to determine the feasibility of turnaround of the subject inside the airlock while encumbered by the spatial limitations caused by the rescuee greatly increased the associated hazards. At each of the gravity levels a safety problem arose. At zero gravity, during two attempts to turnaround, the subject had his relief valve snag on the immobilized subject and be pulled from his suit. At the partial gravity levels, the subject had his helmet air supply inadvertently turned off during the turnaround.

While the rescue maneuver could be performed using a 48-inch diameter cylindrical airlock 72 inches long, it is not advised that both subjects be required to be simultaneously within the airlock. The maneuver would be feasible if the subject were only required to push the immobilized subject into the airlock and close the hatch without entering himself. This can be seen in Tables XV-XVI where the transferance maneuver was successfully completed at each of the gravity levels.

4.4 REPLENISHMENT

4.4.1 OBJECTIVES

The objectives of these tasks were to assess the problems and operational characteristics involved in manual replenishment maneuvers wherein a suited subject (3.5 PSIG) was required to transport a package through the airlock while performing a normal ingress-egress maneuver involving turnaround.

The characteristics investigated were:

- Feasibility of ingress-egress while encumbered by packages.
- Effects of package geometry on task performance.
- Benefits derived from the employment of external traction aids on replenishment performance.
- Effect of gravity level variation on task performance.

These characteristics were investigated using three different package configurations of equal volume. The techniques of analysis described in Section 4.1 were used in the investigation of the operational characteristics. However, because package geometry caused significant performance variances, time-task analysis lacked uniformity between packages. This placed a greater weight on the visual interpretation of the 16mm film for the results and conclusions of this section.

The subjects were required to perform the normal ingress-egress maneuver, detailed in Table III, and were instructed to carry and place the packages as to provide the easiest access.

4.4.2 EQUIPMENT DESCRIPTION

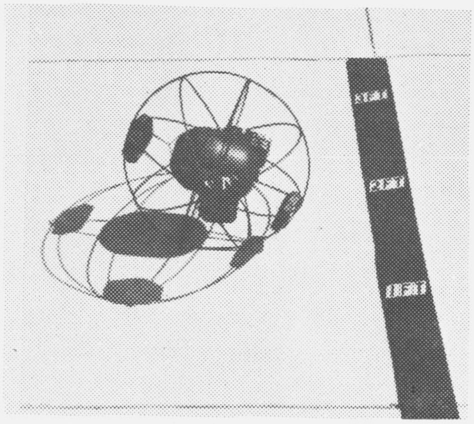
To assess the problems involved in manual replenishment with the reference 48" cylindrical airlock, a series of demonstrations were performed wherein the suited subject was required to transport neutrally buoyant or appropriately weighted packages through the airlock while performing a normal ingress-egress maneuver. The package configurations employed were the following:

- sphere-15" diameter
- cube-13.3" to a side
- cylinder-6.5" diameter, 48" length

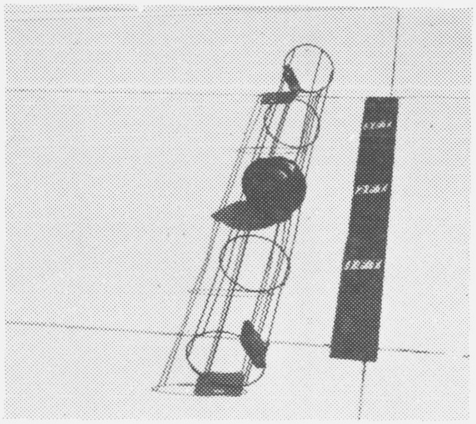
The packages consisted of a bar wire frame with styrofoam floatation material attached to the center of mass of each package to produce neutral buoyancy upon submersion in water and are shown in Figure 4.4-1.

For the reduced gravity condition of 0.08G and 0.16G, the packages were assumed to have a weight of 75 pounds at full gravity. This resulted in a weight of 12.5 pounds at 0.16G and 6.25 at 0.08G. This positive ballast weight was added to the center of mass of each of the packages.

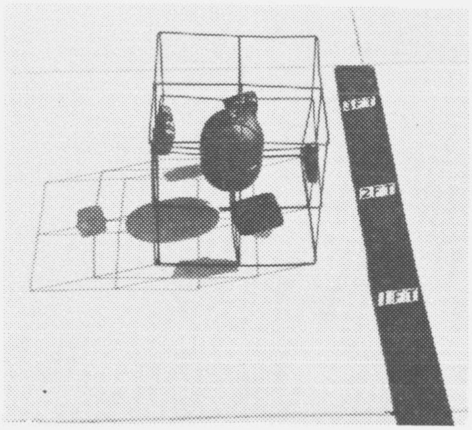
Two subjects in 3.5 PSIG full pressure suits were employed in the zero gravity mode and one subject in the reduced gravity simulation mode.



Spherical Package



Cylindrical Package



Cubical Package

4.4-1 Replenishment Packages

4.4.3 SIMULATED ZERO GRAVITY REPLENISHMENT-TASK 4

4.4.3.1 PERFORMANCE ANALYSIS

4.4.3.1.1 SPHERICAL PACKAGE-RUN 1

Elapsed Time: 0.0 Seconds

This maneuver started with the subject holding the exit bar, with his left hand, while holding the spherical package in his right hand, grasping it with his fingers around one of the wires forming the skeleton frame. He transferred the package to his left hand and steadied himself with his left hand resting on the exit bar while he reached for the oval door latch handle and unlatched the door with his right hand. After pushing the door open, he again took the package in his right hand and the exit bar in his left, reached in and pushed the spherical package into the airlock. His entrance and turnaround to close the oval door were essentially the same as in Task 1 except that as he entered he pushed the package ahead of him to make room for his turnaround.

Elapsed Time: 51.5 Seconds

He moved toward the door opening, pushing against the oval door frame with his left foot, and started his exit from the airlock with his left hand on the door frame and the package in his right hand. On finding it difficult to get through the 32 inch door opening while carrying the spherical package, he released it inside the airlock and reached outside for the tether line which he hooked to the package. He then pushed the package out of the airlock and with the aid of the tether line made a routine exit, turnaround and door closing maneuver similar to Task 1.

Elapsed Time: 105.7 Seconds-End of Maneuver

The return maneuver was performed with one significant deviation. Once inside the airlock, the package was now between the subject and the inward opening door. When he attempted to open the door, he had trouble keeping the packages clear of the door. Once the door was open, he was able to complete the maneuver with little difficulty. Figure 4.4-2 is a photographic sequence of the replenishment maneuver with the spherical package.

4.4.3.1.2 CUBICAL PACKAGE

This maneuver started at the oval door with the subject holding the exit bar with his left hand while holding the cubical package against his body with his right hand. He inched himself along the exit bar with his left hand until he was close enough to reach the oval door latch handle with his left hand. He steadied himself with his feet against the base of the airlock while unlatching and opening the door with his left hand. As the door opened he pushed the package into the airlock with his right hand, released it and completed opening the door by pushing it with his right hand while holding the exit bar with his left hand. He started his entrance with his right hand at the bottom of the door frame and his left hand on the exit bar. The remainder of the entrance maneuver was made in a routine manner similar to Task 1 up to the point where he was ready to exit the circular door.

After opening the door with his left hand on the hand grab inside the airlock and his right hand on the door latch handle, he started turning to his left as he exited until he could reach the tether line with his right hand. By the time his legs were out of the airlock he was facing back toward the oval door with his head about 2 feet above the level of the top of the airlock. He pulled himself down, using the tether line in his right hand until he could reach into the airlock with his left hand for the package. He pulled it towards him until he could take it out of the airlock, holding it with both hands. Then, holding the package against his body with his right arm while holding the tether line in his right hand, he completed this maneuver by closing the circular door with his left hand. The subject was able to perform the proceeding task from the circular door to the oval door in a similar manner.

4.4.3.1.3 CYLINDRICAL PACKAGE

This maneuver started with the subject holding the exit bar with his left hand. While his right hand unlatched and opened the oval door, the cylindrical package was held between his body and the end of the airlock. He pushed the package into the airlock with his right hand, then made a routine entry pushing the package ahead of him as he entered. He turned around, closed the oval door, turned around again and opened the circular door in a routine manner with little or no interference from the package resting on the bottom of the airlock.

After the door was opened, he steadied himself with his left hand on the handhold inside the airlock while he picked up the package with his right hand. He used both hands to push it out as his body was emerging. As his hips passed the circular door opening he held the package under his right arm while he grasped the tether line with his left hand. He used his feet against the door frame to turn his body to his left, and as he completed the turnaround he switched hands on the tether line. He held his position with his right hand pulling on the tether line and his right arm holding the package against his body, while he closed and latched the circular door with his left hand. The subject was able to perform the task proceeding from the circular door to the oval door in a similar manner.

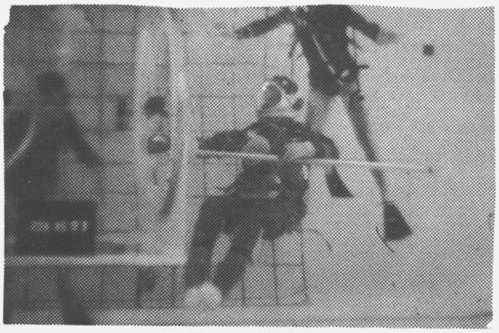
4.4.3.2 RESULTS

The time-motion and limb angle analysis is summarized in Figures 4.4-3-4.4-14 which show the relationship between the ingress-egress task performed with the subject carrying the transfer packages and the Task 1 normal ingress-egress maneuver.

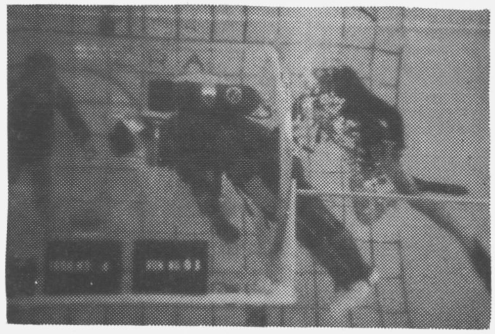
In general, it can be seen that the additional task of carrying transfer package while performing the ingress-egress maneuver significantly increased both subtask and total performance times. This increase in performance time was caused principally by the additional time required to manipulate the packages in a full pressure suit.

Because of diminution of tactual cues afforded by the pressure suit, the subjects could only determine contact with the packages by visual means. On one occasion, the cube drifted away from the subject before he realized that contact had been lost.

The test indicated that the subject required more control over the transfer packages. The practice of holding the package under his arm was inefficient in a pressure suit. The reduced vision and tactual feedback afforded by the pressurized suit increases the probability of package loss. To compensate for this, two aids should be incorporated: (1) a handle should be attached to the package to allow more positive control over the package, (2) a tether attached between the package and the subject. This would enable the subject to retrieve a package if it began to drift away.



Open Door



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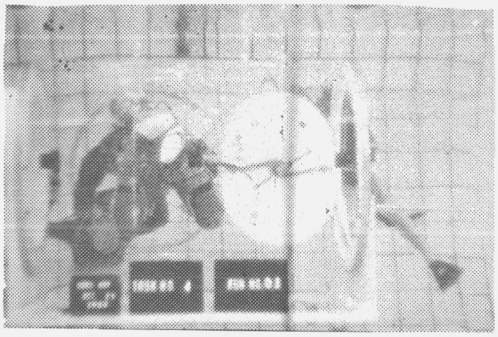
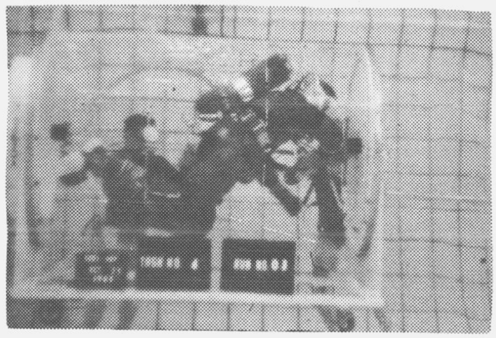
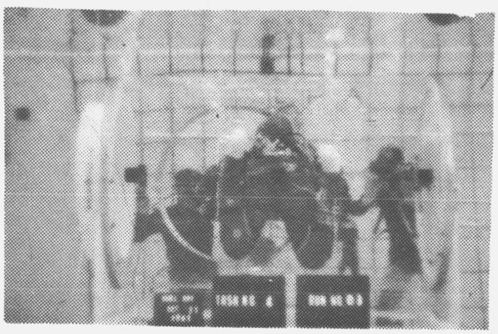


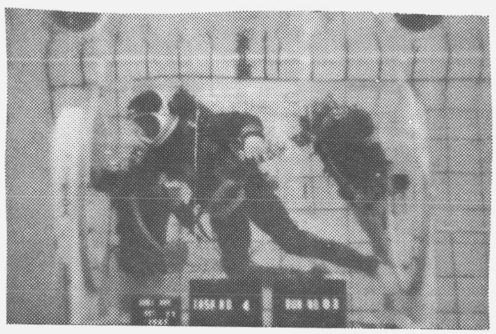
Turnaround



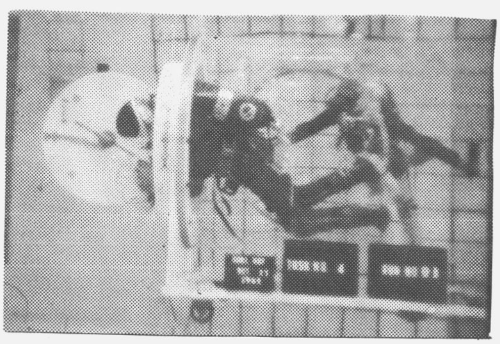
Close Door



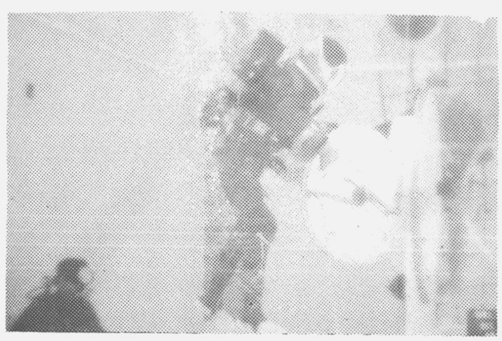
Turnaround



Open Door

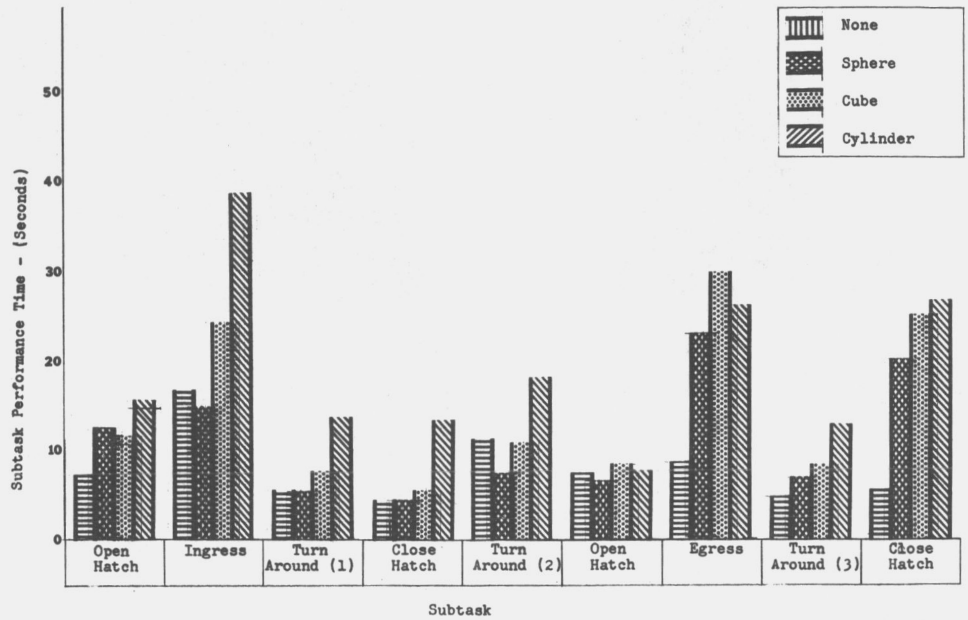


Exit



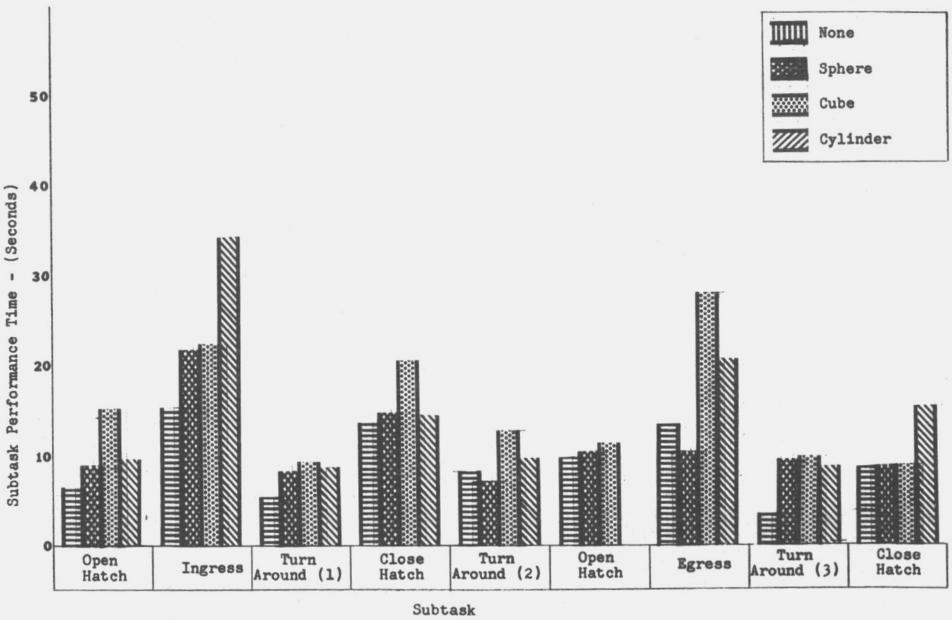
Close Door

4.4-2 Sequence of OG Replenishment - Spherical Package



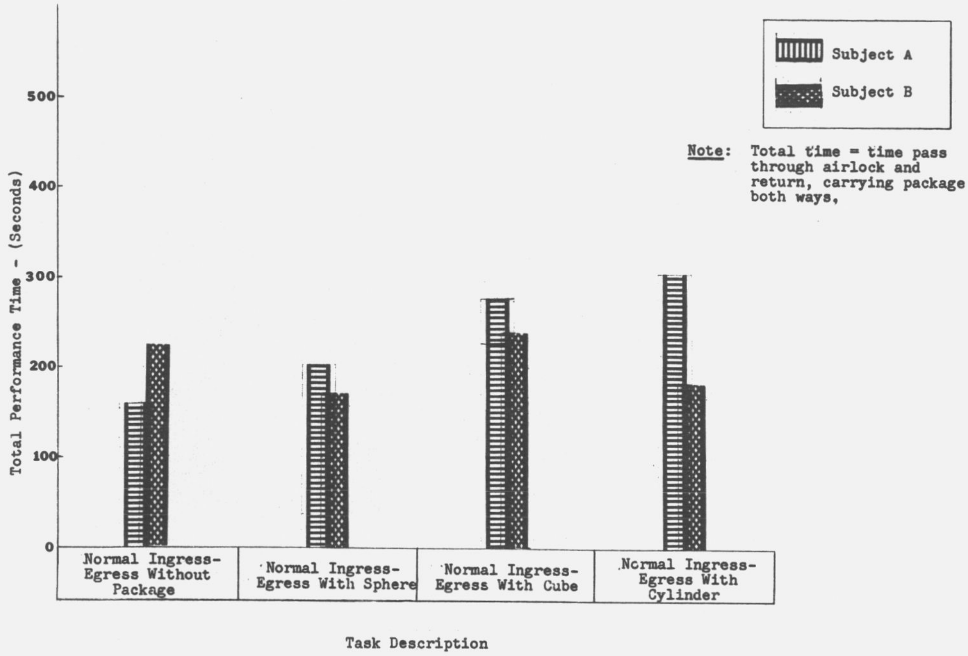
The Effect of Package Geometry on Subtask Performance Time Subject A Direction O-C

Figure 4.4-3



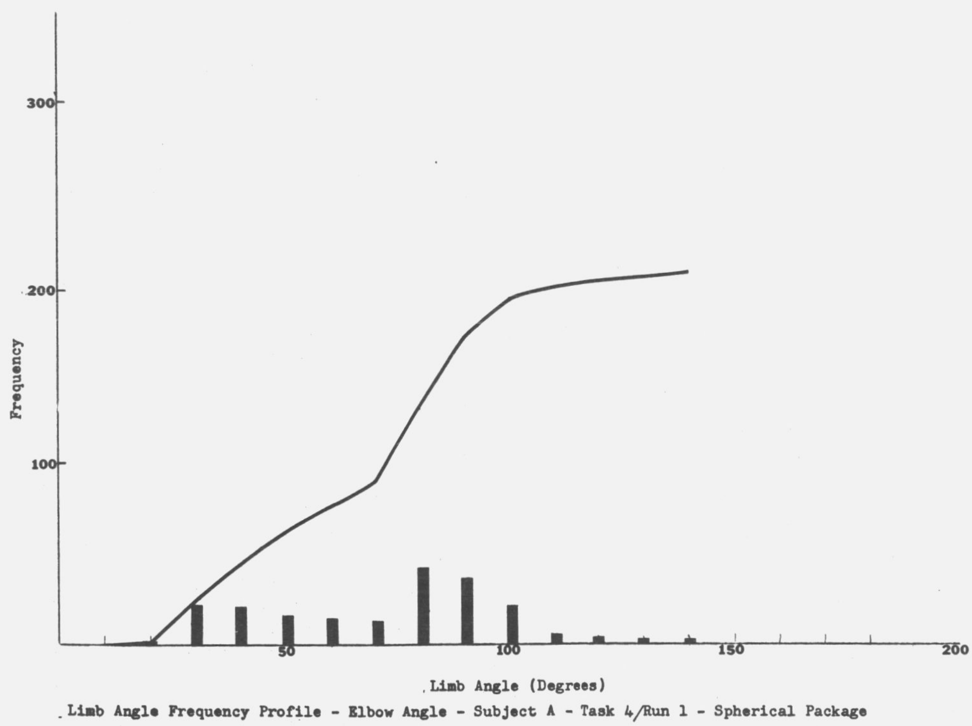
The Effect of Package Geometry on Subtask Performance Time Subject A Direction C-O

Figure 4.4-4



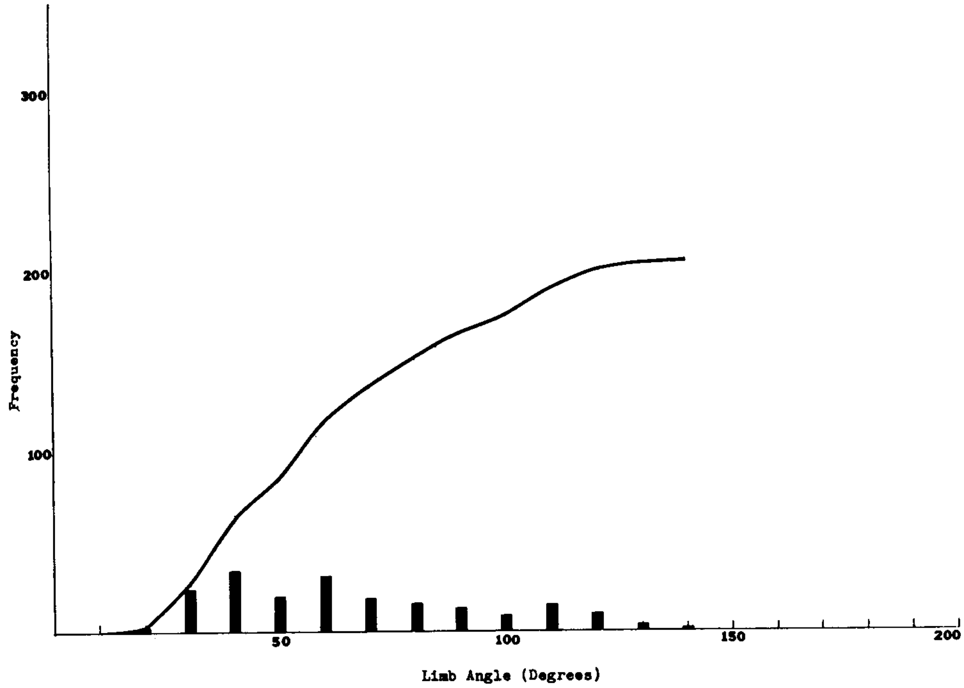
Comparison of Total Times For Two Subjects and Three Packages

Figure 4.4-5



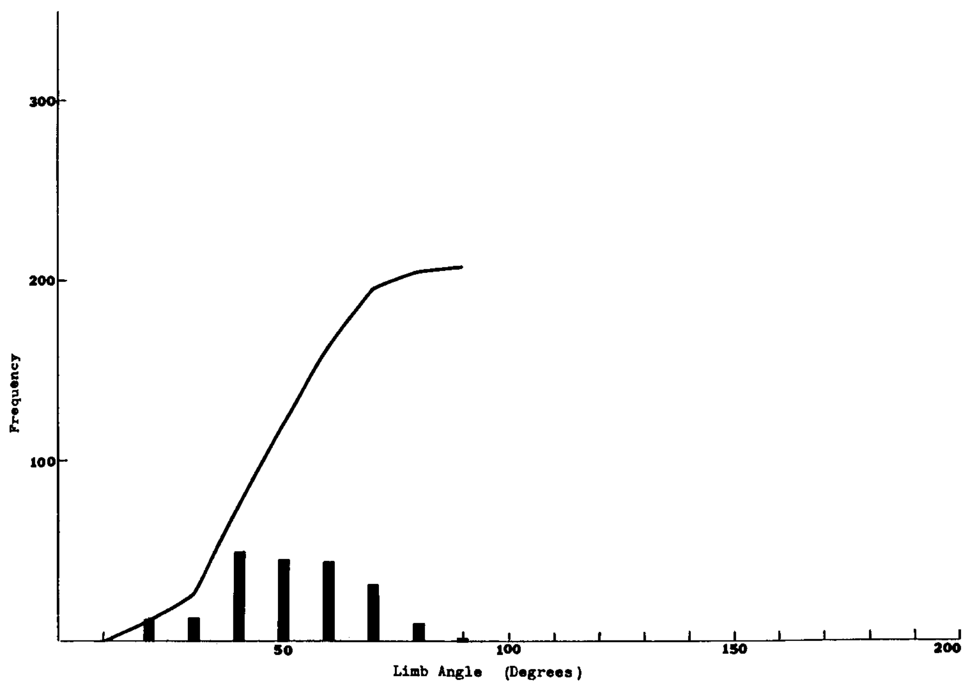
Limb Angle Frequency Profile - Elbow Angle - Subject A - Task 4/Run 1 - Spherical Package

Figure 4.4-6



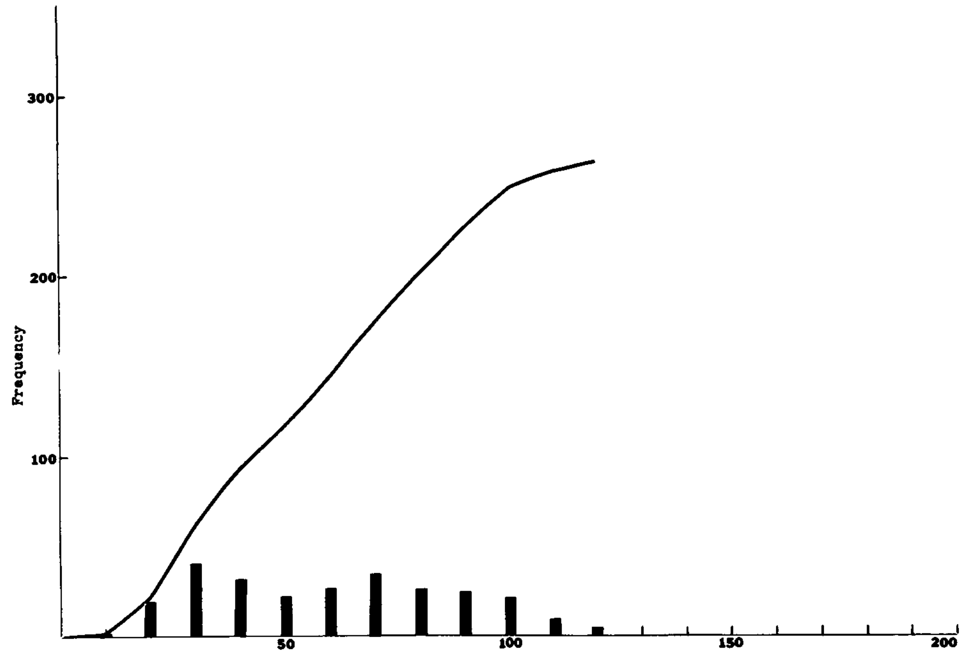
Limb Angle Frequency Profile - Knee Angle - Subject A - Task 4/Run 1 - Spherical Package

Figure 4.4-7



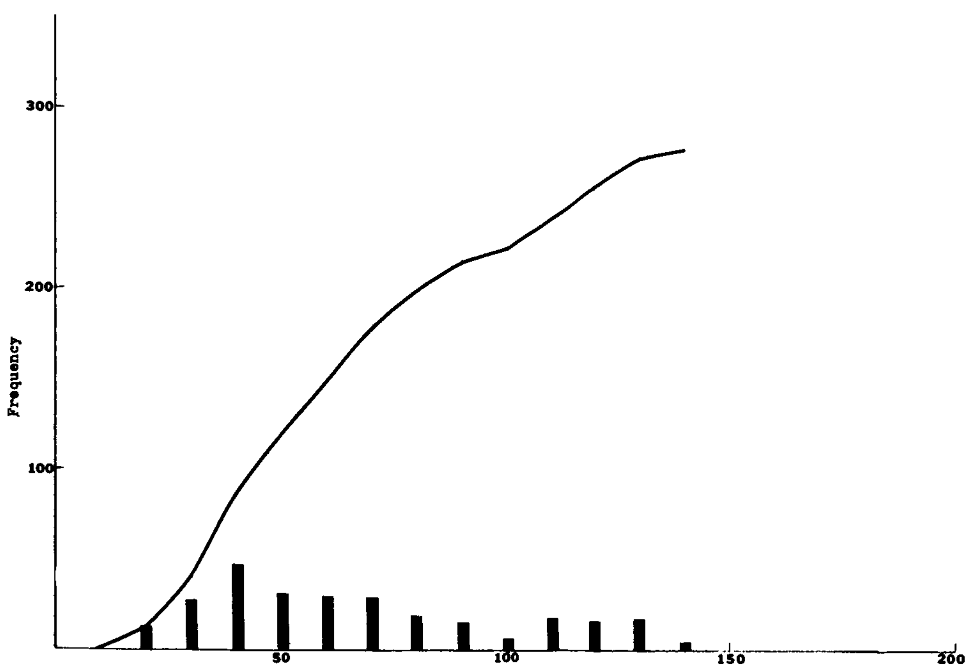
Limb Angle Frequency Profile - Hip Angle- Subject A - Task 4/Run 1 - Spherical Package

Figure 4.4-8



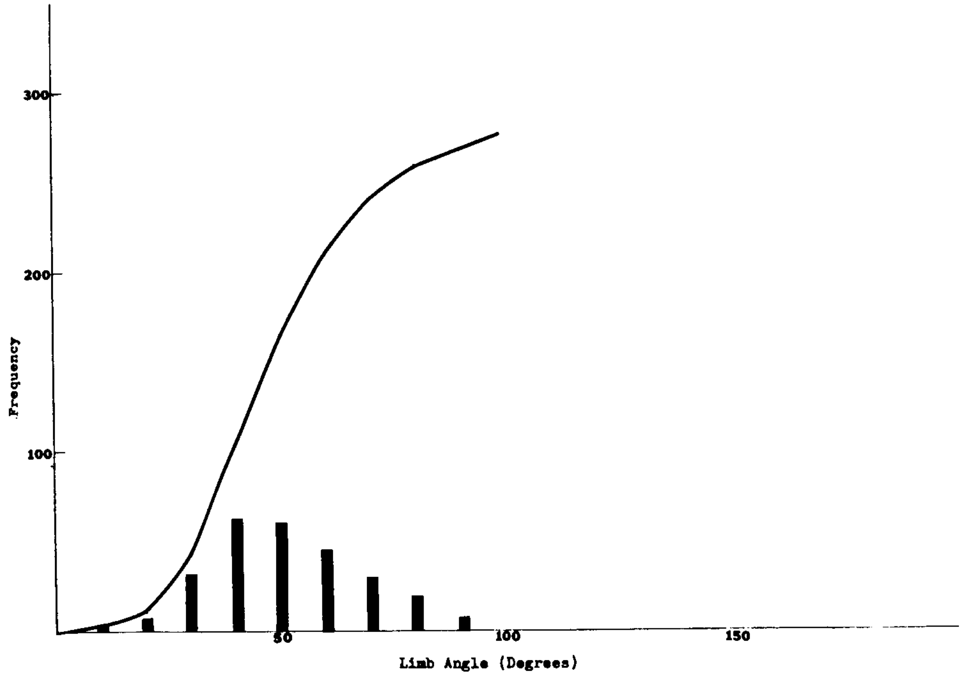
Limb Angle Frequency Profile - Elbow Angle - Subject A - Task 4/Run 6 - Cubical Package

Figure 4.4-9



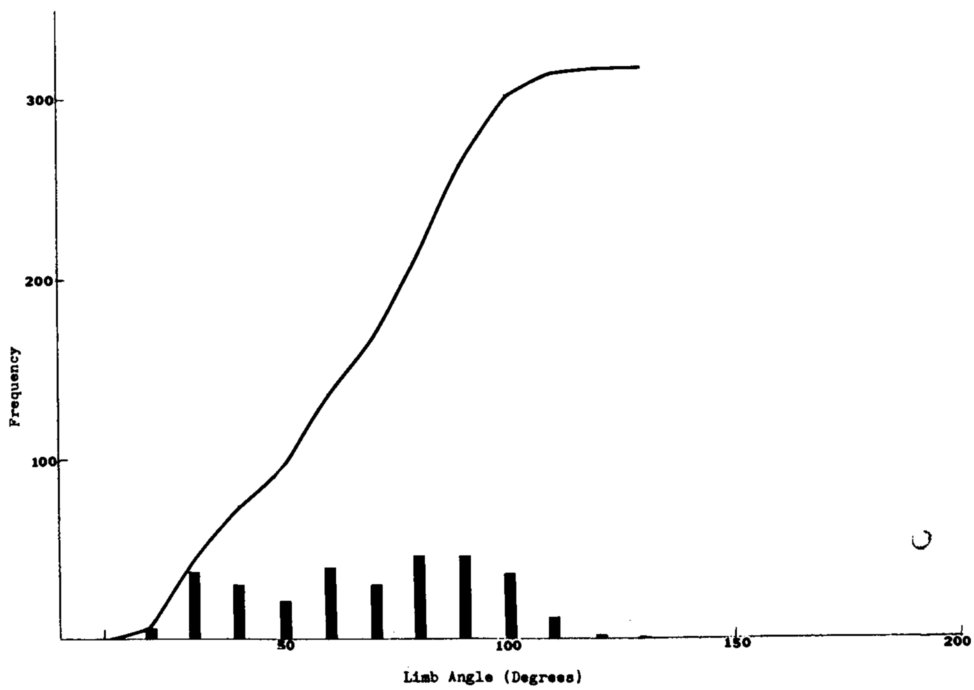
Limb Angle Frequency Profile - Knee Angle - Subject A - Task 4/Run 6 - Cubical Package

Figure 4.4-10



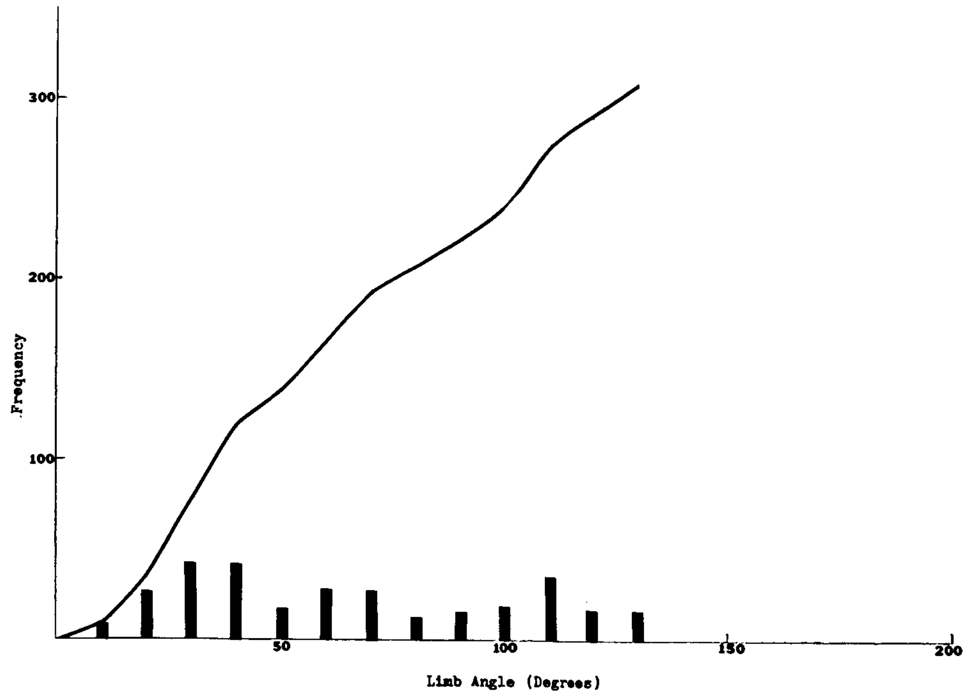
Limb Angle Frequency Profile - Hip Angle - Subject A - Task 4/Run 6 - Cubical Package

Figure 4.4-11



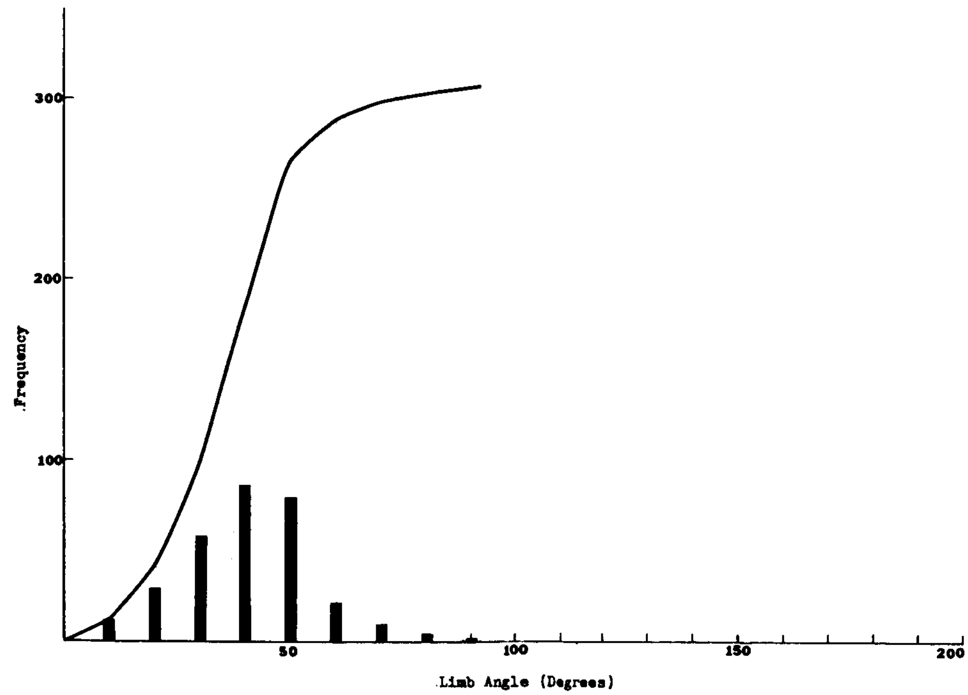
Limb Angle Frequency Profile - Elbow Angle - Subject A - Task 4/Run 7 - Cylindrical Package

Figure 4.4-12



Limb Angle Frequency Profile - Knee Angle - Subject A - Task 4/Run 7 - Cylindrical Package

Figure 4.4-13



Limb Angle Frequency Profile - Hip Angle - Subject A - Task 4/Run 7 - Cylindrical Package

Figure 4.4-14

4.4.4 DEMONSTRATION OF REDUCED GRAVITY REPLENISHMENT-TASK 16

4.4.4.1 DISCUSSION

These tasks were performed with the same package configurations used for the zero gravity replenishment maneuver, except that they were ballasted to simulate a 75 pound package at full gravity. This resulted in a net weight of 6.25 pounds at 0.08 gravity and 12.5 pounds at the 0.16 gravity level case.

The positive weight of these packages caused significant differences in package handling. The subject no longer exited the airlock and then returned for the package, but placed the package outside the airlock before making his exit. A performance sequence for the replenishment maneuver is shown in Figure 4.4-15.

As in the normal ingress-egress maneuver, the exit bar and door handle were necessary for a successful exit. The subject also required use of external aids when picking up the package. Pressure suit restrictions prohibited him from stooping to pick them up, forcing him to lean forward. He found that the only way in which he could regain a standing position was to use the exit bar and tether to pull himself up.

The subject also found that the door opening maneuver became more difficult when executed by the subject external to the airlock with the addition of positive weight to the transfer packages. It was observed that the packages became harder to hold with one arm while opening the door with the other hand. In this respect, the subject found that the exit bar offered a suitable support for the package while he opened the door. The tether line, however, did not appear to aid the subject during this maneuver.

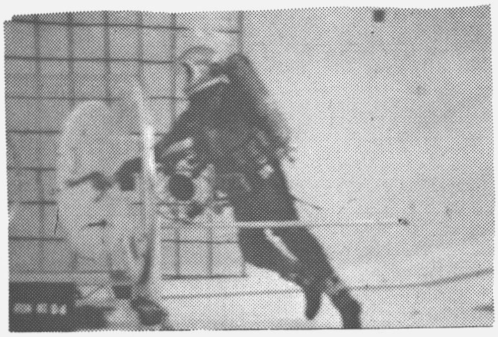
As the packages were transferred from 0.08 to 0.16 gravity, the turnaround maneuver took on increased difficulty. The subject found that the packages were always in his way, always underfoot. (Figure 4.4-15). This caused an increase in turnaround time of 14%, 35%, and 33% for the sphere, cube and cylinder, respectively at the higher gravity level.

4.4.4.2 RESULTS

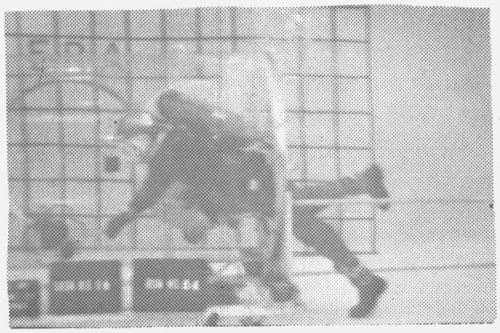
The task performance times are given in Figure 4.2-50 which shows the relationship between the replenishment tasks at reduced gravity and at zero gravity. As in the modified ingress-egress maneuver, task performance time was a minimum for the 0.08 gravity level.

The addition of a positive weight to the packages posed new problems in handling. The subject had to place the packages on the floor before exiting and then pick them up after his exit. Because of reduced kinesthetic feedback in the full pressure suit it became apparent that the subject could not have regained a standing position after picking up the packages without the support rendered by the airlock and associated hardware.

As the packages were transferred from 0.08 to 0.16 gravity, the turnaround maneuver took on increased difficulty. The subject found that the packages were always in his way, always underfoot. This caused an increase in turnaround time of 14%, 35%, and 33% for the sphere, cube and cylinder, respectively, at the higher gravity level.



Open Door



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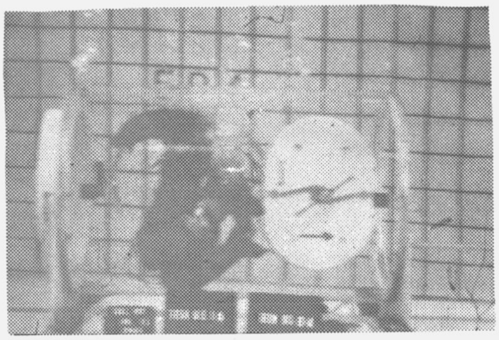
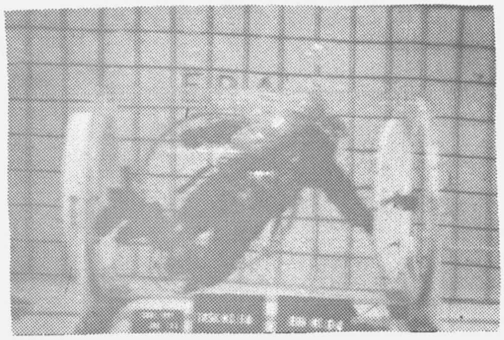


Turnaround



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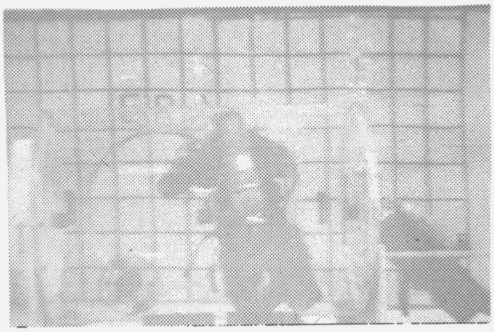
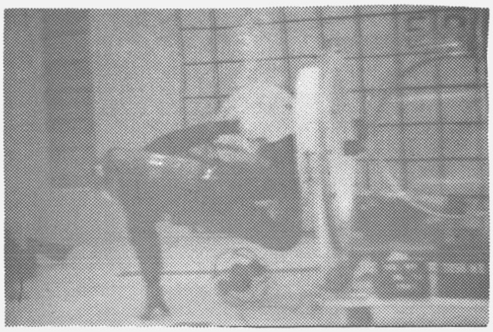
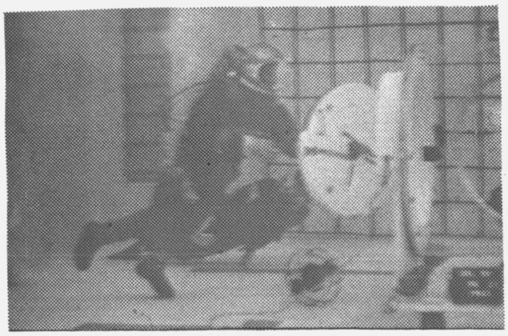


Turnaround

Open Door



Exit



Close Door

4.4-15 Sequence Of Simulated Reduced Gravity Replenishment

4.4.5 CONCLUSIONS

Visual analysis of the film record shows that manual replenishment by a full pressure suited subject is feasible for the package geometries investigated. Task performance indicates definite need for external traction aids and a package restraint system. In the simulated zero gravity condition, the subjects had great difficulty performing the entry maneuvers. This maneuver required the manual operation of the hatch latching mechanism and the opening of the hatch while maintaining body position using the external traction aids and holding the replenishment package. The loss of tactual cues afforded by the full pressure suit plus the complexity of this task did not allow the needed control required for manipulation of the packages. On one occasion the combination of these factors allowed the cubical package to drift away unbeknownst to the subject.

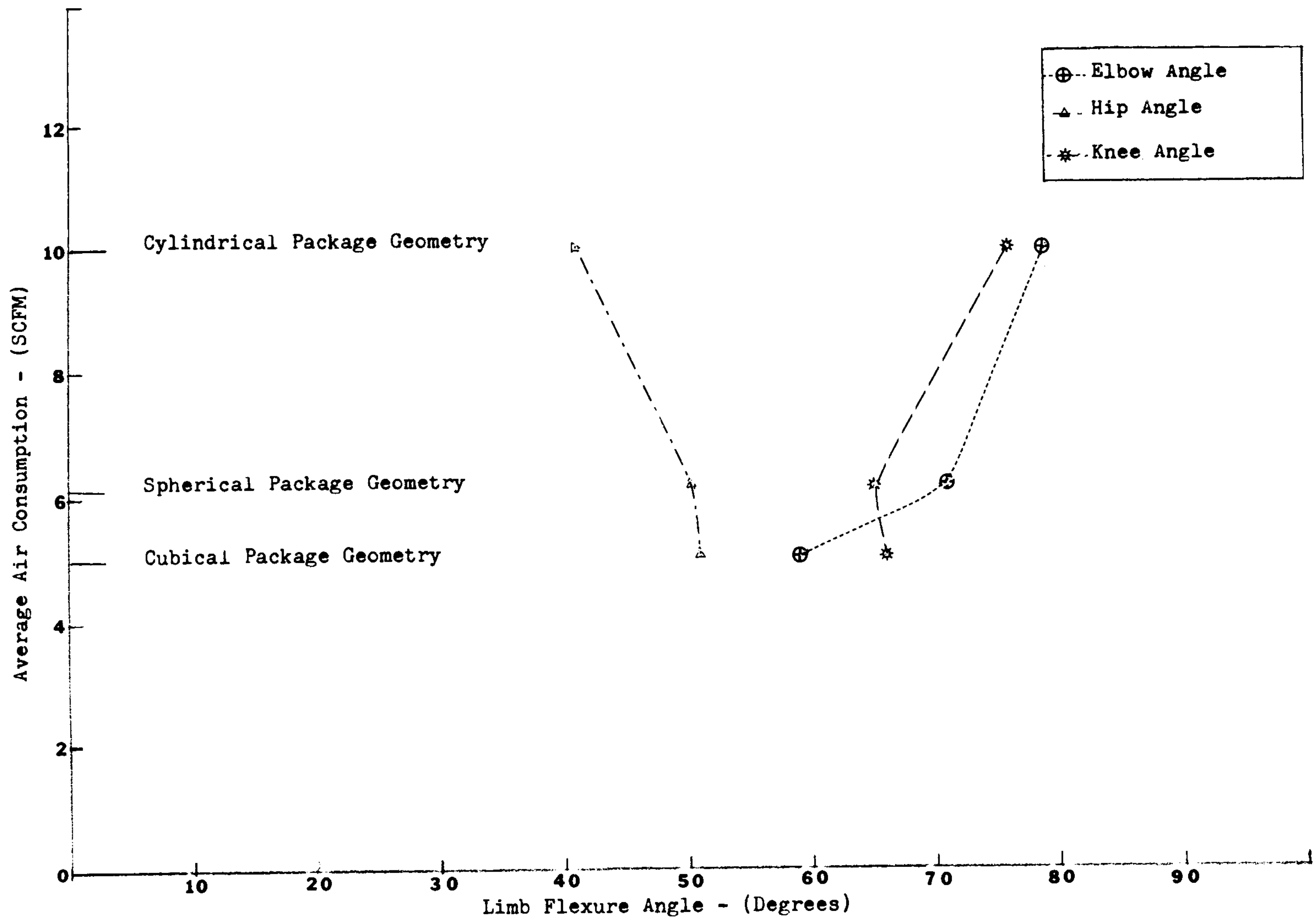
In the reduced gravity situations, the maneuver was more directly hampered by the tactual decrements and limitations of the external traction aids. Because the packages had positive weight, it became increasingly difficult to hold onto them while unlatching and opening the hatch. The rigid exit bar supplied a support on which the packages could be rested during the hatch opening maneuver. The safety tether did not supply this needed support.

Under reduced gravity conditions, the sill height, the distance from the bottom of the hatch to the floor, became important. During the entry, the subject associated hardware tended to become snagged on the sill. While performing the exit head-first, there was a tendency to fall out of the airlock. This was partly alleviated by the rigid support supplied by the exit bar but not by the tether. In general, the sill height should be lower than the 18 inches used in these tests.

Replenishment packages should be provided with a means of restraint, e. g. handle or short tether line. This would help to compensate for the tactual decrements and reduce package loss problems.

Subjective comments produced an ordering of preferred package geometry. Rank preference yields the following ordering from most preferred to least preferred: (1) sphere, (2) cylinder, (3) cube.

Air usage indicates the following order from least energy expenditure to highest expenditure: (1) cube, (2) sphere, (3) cylinder. The ordering by energy expenditure was extracted from Figure 4.4-16. This seems to indicate that the optimum package geometry lies somewhere between a true spherical or cubical shape; however, sufficient data has not been accumulated to provide conclusive results in this area.



The Effect of Package Geometry on Average Air Consumption During OG Replenishment Task

Figure 4.4-16

4.5 TORQUE

4.5.1 OBJECTIVES

In previous sections of this report various airlock models were used to investigate ingress-egress and related tasks. These models, while incorporating dimensional-working replicas of representative latching configurations did not include associated latching torques as this would complicate the kinematic analysis of subject motion used to determine dimensional optimazation. The ability of man to exert torque forces while restrained or unrestrained is, however, an extremely important aspect of ingress-egress related maneuvers.

The following section details the effort during the contract related to the investigation of torque application in a simulated tractionless environment.

The torque tasks investigated were designed to evaluate man's capability to apply torque forces while internal and external to an airlock. The objective of these tasks was to determine the effectiveness of the subject's force application to setting a latch handle into rotation by investigating the following factors:

- Maximum torque capacity
- Maximum angle of rotation at a pre-selected torque level
- Plane of force exertion
- Use of handholds and footholds

Replicated experiments were run at 0, 0.16, 0.08 and 1 G_e. The 0, 0.16, 0.08 G_e variations were performed in the water immersion simulation mode. The various initial subject body positions are shown in the Figures 4.5-1.

The subject was required to exert torque on a test panel by either placing both hands on the operating handle or by placing one hand on the operating handle and one in the restraint handle. No attempt was made during this phase of the contract to vary the restraint handle position. The subject also employed the foot restraints in conjunction with the handholds. Water immersion simulation tests were conducted with the 6' long 48" diameter airlock and torque panel resting on the bottom of the pool in approximately nine foot depth of water, with the torque panel located adjacent to the circular hatch.

Task variations external to the airlock were conducted with the subject in a horizontal orientation with feet extending away from the torque panel and/

or the subject in a vertical orientation in front of the test panel with his feet on the foot restraint provided.

4.5.2 EQUIPMENT DESCRIPTION

Two parameters were measured; maximum torque for several initial handle orientations and angle of travel for several fixed level of handle torque. Tests were designed to use a pressure transducer and potentiometer to record torque and angle of rotation on a strip chart recorder. The system was operational for ground tests, but on submersion of the panel in water, the system picked up interference through the water giving sporadic and erroneous readings. As a consequence, the system was rebuilt to allow manual recording of data read from a remote pressure gage and direct readings of angle of rotation from an indicator affixed to the latch handle shaft. Measurements were accumulated by direct observations of a pressure gage attached to a hydraulic cylinder located in a fixed orientation to a sprocket wheel and chain drive. Measurements of the angular travel of the sprocket relative to the fixed drive shaft were obtained.

The torque test device, Figure 4.5-2, was constructed to simulate the latch action of the cylindrical airlock configuration. The panel was constructed to operate in two data modes:

- Maximum torque qpplication at preset handle angles-(1)
- Maximum angle of handle rotation for preset torque levels-(2)

(1) the torque device was fitted with a hydraulic cylinder which transmitted the hydraulic pressure produced by torque application to the handle to a remote pressure gage. Calibration of the system was performed using a 0-120 foot/pounds torque wrench to determine the relationship of pressure to torque. (2) a mechanically adjusted clutch was fixed to the shaft supporting the latch handle. Manual adjustment was accomplished by varying clutch spring pressure until slippage occurred at the desired torque level. An indicator was mounted on the shaft to visually indicate the degree of rotation.

A handle was attached to the face of the panel on the right-hand side to provide restraint. Footholds outside the airlock were provided by means of metal stirrups attached to the base of the torque device. Inside the airlock, the footholds were comprised of metal stirrups suspended approximately 6" below the airlock axis and 5' from the end of the airlock at which the panel was located.

4.5.3 PERFORMANCE ANALYSIS

The task was performed in two modes. They were:

(I) Subject standing erect in front of torque panel with feet constrained by foot-holds.

(II) Axis of subject's body perpendicular to the plane of the torque panel.

In both cases, the subject was required to exert torque under the following conditions:

(1) with one hand on the latch handle and the other grasping a restraint handhold while his feet were constrained by footholds (designated as "with handhold" in text).

(2) with both hands on the latch handle and the feet constrained footholds (designated as "without handhold" in text)

(3) while in Mode II position, exert torque with both hands on the latch handle and the feet unrestrained.

The test variations are shown in Figure 4.5-1.

In all cases the subject was required to exert maximum torque with the handle at varying degrees with respect to the vertical and to produce maximum rotation of the latch handle at a preset torque level.

From the film analysis and subject comments, it was apparent that the handhold provided was inadequate for use in a full pressure suit although adequate in the unpressurized mode. The subject complained of the handhold being too small for the insertion of their hand while pressurized. To a lesser degree, the same effect was observed during the use of the footholds.

While exerting torque in Mode II, zero gravity, the subject first produced a counter rotation of their body and then a rotation in the direction of handle travel to augment body inertia while exerting torque. The same procedure was attempted in the reduced gravity case, but the subject found that this maneuver caused his feet to come out of the footholds. During the test performance, four full pressure suits were damaged in the foot area due to the constraints of the foot-holds. These damages occurred mainly during Mode II when the subject was suspended between the torque panel and the footholds.

4.5.4 RESULTS

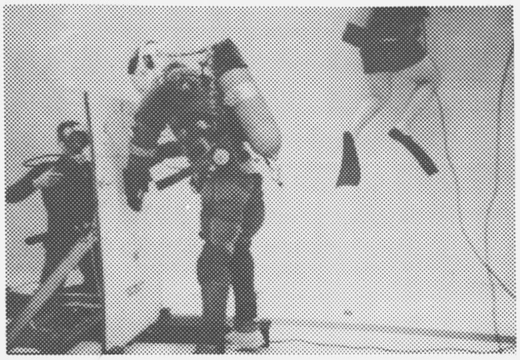
The purpose of these tests was to determine the gravity level dependence on the effectiveness of the subject's force application to setting a latch handle into rotation.

The results of tests to determine the subject's maximum torque capacity is shown in Table XVII and are graphically shown in Figures 4.3-3 and 4.3-4. These figures show the relationship between maximum exertable torque and latch handle angle. Figure 4.3-5 shows the variation of the angle of rotation of the latch handle for a preset torque level. It can be seen in Figure 4.5-3 that for the $1G_e$ condition, Mode I, the maximum exertable torque increased as the handle angle increased from 0^o to 90^o. This condition existed whether torque was exerted with or without the handhold.

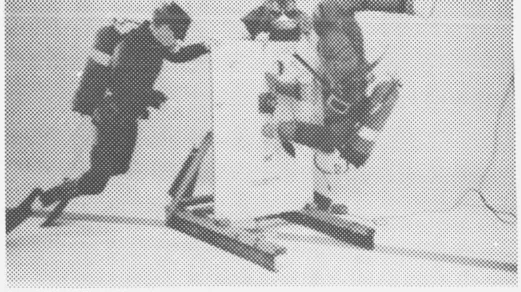
When the simulated gravity level was changed to zero, the maximum torque did not increase as the latch handle angle went from 0^o to 90^o but remained fairly constant.

Figure 4.5-4 shows the results obtained when the tests were performed in Mode II, inside the airlock. In contrast to the Mode I case, Figure 4.5-3, there is not as great a variation between the gravity levels.

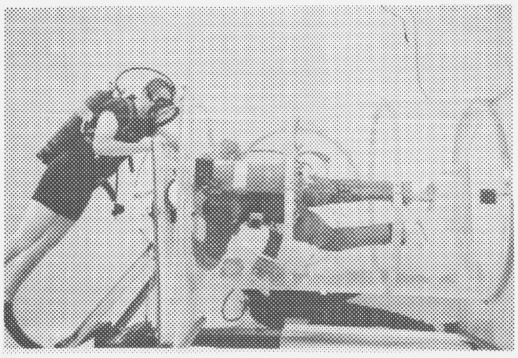
Figure 4.5-5 shows the results of the measurements of maximum angle of latch handle rotation for a pre-determined torque level setting. In the unrestrained condition, the maximum angle of rotation increased as the gravity level increased from OG to 0.16G. For the other modes the maximum angle of rotation occurs in the zero gravity condition.



Subject Standing Erect In Front of Torque Panel
Constrained By Foot-Holds

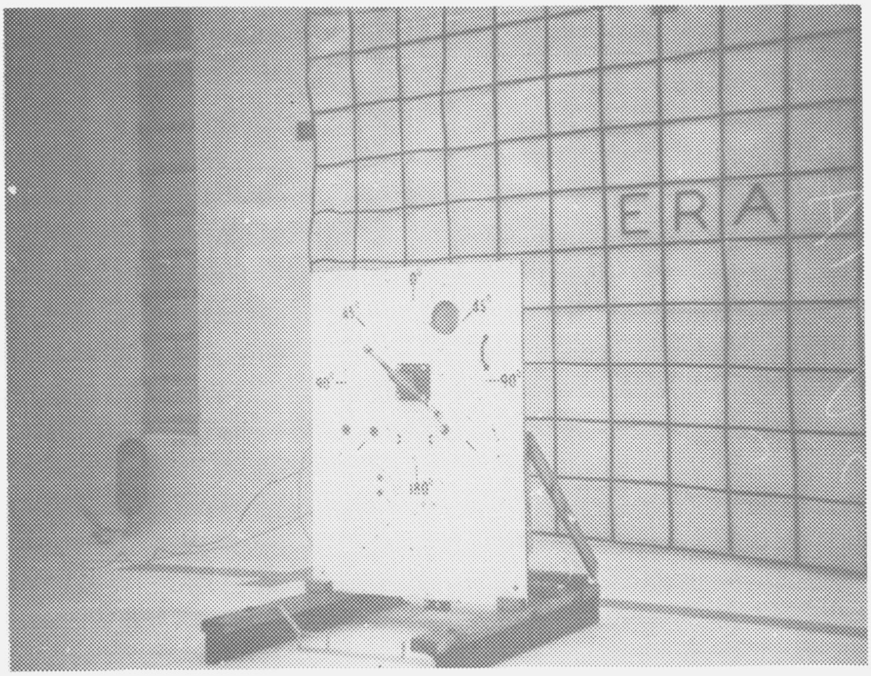


Subject Unrestrained In Front of Torque Panel



Subject Perpendicular to the Torque Panel
While Interior To The Airlock

4.5-1 Initial Torque Exertion Positions



4. 5-2 Torque Test Panel

4.5.5 CONCLUSIONS

Test results have shown that the application of torque by a full pressure suited subject is dependent upon the following factors:

- Simulated gravity level
- Subject orientation relative to the torque test device
- The use of torque induced motion restraints.

As seen in Figure 4.5-3, 4.5-4, the exertion of torque was less sensitive to gravity level as the gravity level was decreased. In the $1G_e$ condition, the subject was able to employ his weight to better and better advantage as the latch handle angle changed from 0^o to 90^o with respect to the vertical. In the simulated zero gravity condition, the subject could no longer employ his weight but had to rely on body inertia and strength to produce torque. Under the partial gravity conditions, the maximum torque output no longer increased with latch handle angle. The magnitude of the torque exerted with the subject oriented with the frontal plane of his body parallel to the torque test device was greater than those torque applications performed when the subject's body was perpendicular to the test device.

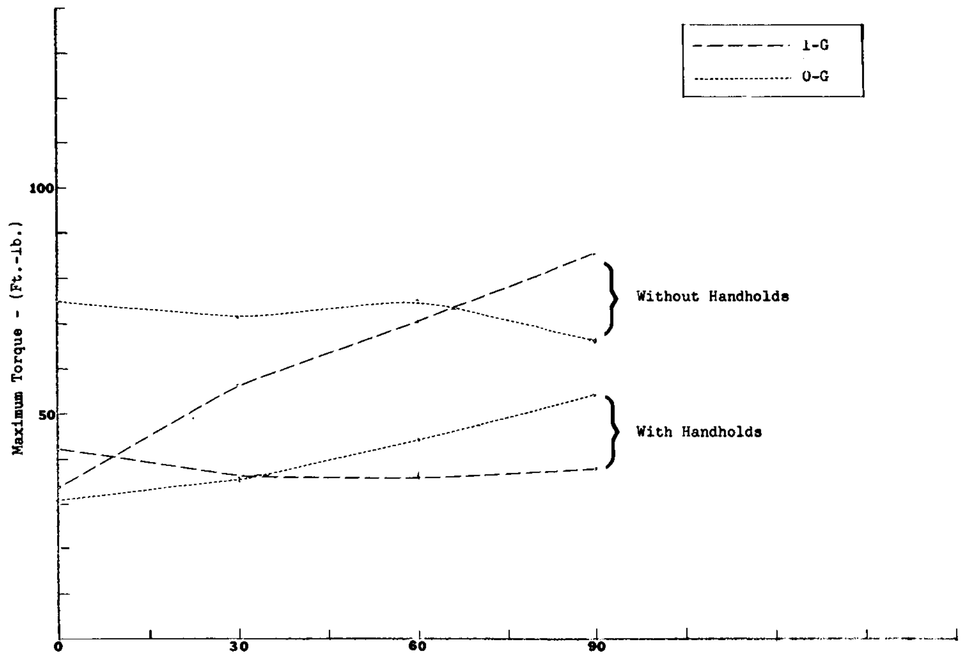
In general, the use of hand and foot restraints enhanced the subject's positioning ability for the application of torque. The restraints permitted a continuous application of torque. While these restraints did inhibit torque induced motions, the test subjects were able to produce a higher absolute torque if they produced a rotation and then a counter rotation with their body to produce a rotational velocity in the direction of latch handle travel to augment their torque capability inside the airlock. This was most apparent at the zero gravity level. As the simulated gravity level was increased to 0.08G and 0.16G, the synchronization of body rotation and torque application became increasingly difficult due to the increase of body mass and the two point suspension of the subject between the test device and foot restraints.

Figure 4.5-6 shows the maximum exertable torque with the latch handle at 0^o inside the airlock at different gravity levels and indicates that while motion restraints permit a continuous application of torque, the unrestrained condition allows the application of non-continuous torque approximately 44% greater. From the figures it can be seen that torque exerted with two hands on the latch handle is greater than one hand on the latch handle and the other secured by a handhold. It can also be seen that both hands on the latch handle permit a greater handle rotation than only one hand on the latch handle.

TABLE XVII - SUMMARY OF MAXIMUM TORQUE OUTPUT FOR VARIOUS INITIAL HANDLE ANGLES

	Initial Handle Setting	Outside the Airlock					Inside the Airlock								
	Degrees	1 G, with handholds[1]	1 G, without handholds	0 G, with handholds[1]	0 G, without handholds	0 G, no restraints	1/6 G, with handholds[1]	1/6 G, without handhold	1/6 G, no restraints	1/12 G, with handhold[1]	1/12 G, without handhold	1/12 G, no restraints	0 G, with handhold[1]	0 G, without handhold	0 G, no restraints
SUBJECT A	0	33.1	36.0	41.3	89.0	61.1	23.1	43.4	65.4	19.3	52.0	70.1	25.6	57.9	62.6
	30	31.6	46.7	32.4	76.3	X	19.6	43.9	X	20.5	61.6	X	26.5	59.6	X
	60	42.5	60.2	34.1	90.1	X	19.3	46.4	X	14.5	54.0	X	15.9	53.4	X
	90	53.0	76.8	33.1	75.0	X	14.5	38.4	X	14.9	38.7	X	20.7	50.0	X
SUBJECT B	0	31.6	32.1	40.5	60.6	33.6	X	X	X	X	X	X	14.8	22.4	48.5
	30	39.4	66.3	38.8	65.8	X	X	X	X	X	X	X	13.7	23.5	X
	60	43.4	79.0	37.8	68.0	X	X	X	X	X	X	X	11.8	19.6	X
	90	54.1	83.7	41.6	56.9	X	X	X	X	X	X	X	13.9	22.3	X

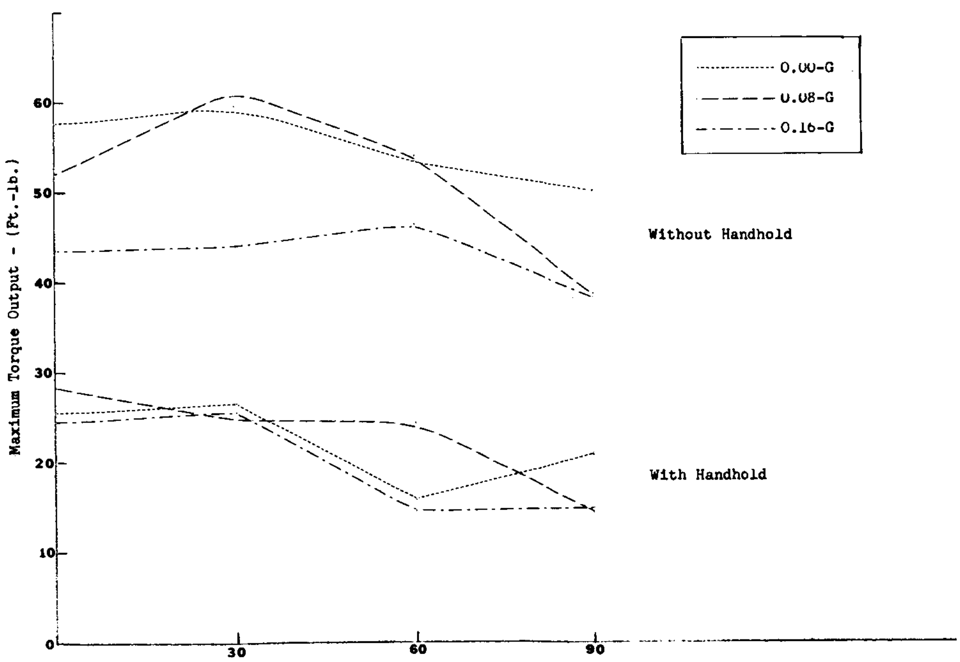
(1) Subject's feet restrained by fixed footholds. X = N. R.
Torque values in body of table given in #-FT.



Handle Orientation Angle - (Degrees)

The Effect of Initial Handle Orientation on Maximum Torque Capacity Subject A Outside Airlock

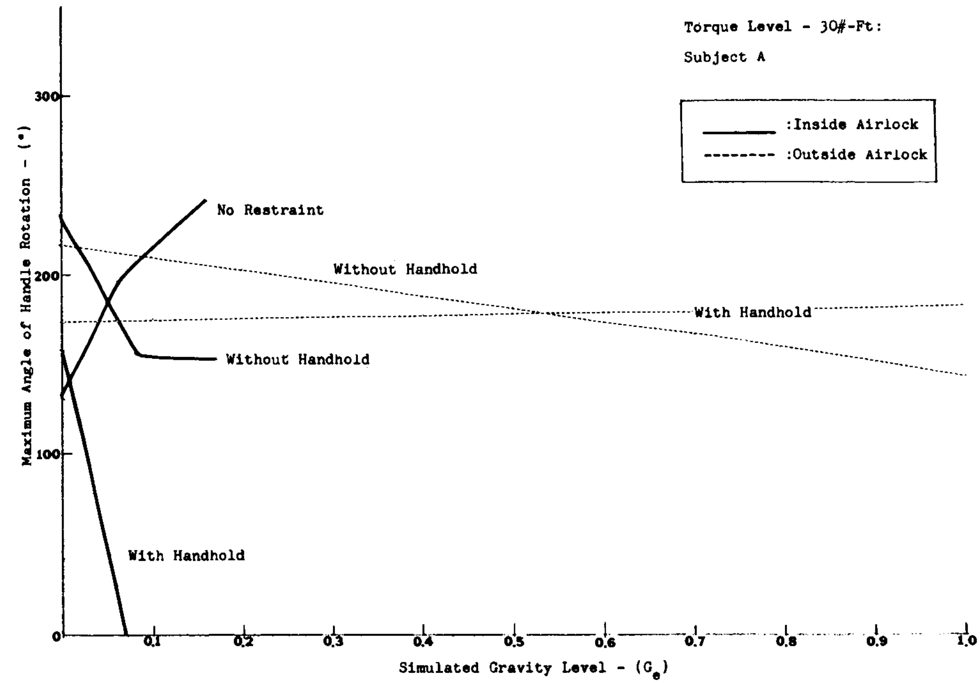
Figure 4.5-3



Handle Orientation Angle - (Degrees)

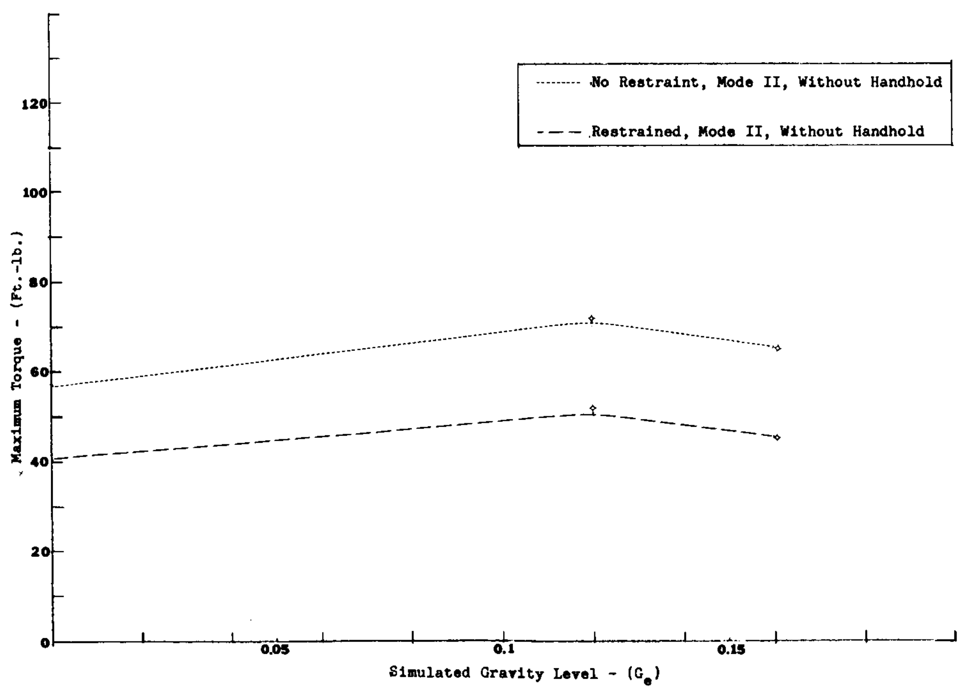
The Effect of Initial Handle Orientation on Maximum Torque Capacity Subject A Inside Airlock

Figure 4.5-4



The Effect of Gravity Level Variation on Handle Rotation at a Present Torque Level

Figure 4.5-5



The Effect of Gravity Level Variation on Maximum Torque Capacity Subject A Inside Airlock

Figure 4.5-6

4.6 EXTERIOR MANEUVERS

4.6.1 GENERAL

To complete the simulation effort of this phase on the performance of astronaut ingress-egress and related tasks a series of demonstrations of maneuvers exterior to airlock configuration were run. These tasks included:

- Maneuvers about the exterior surfaces of the airlock configurations.
- Walking at 0.08, 0.16 G_e
- Personnel transfer between configurations

The intent of this effort was to provide cursory, visual data on these maneuvers to assess the feasibility of performance and to ascertain whether water immersion simulations were applicable. The hardware and mock-ups utilized during these tasks were the same as used for the previously described tasks.

4.6.2 MANEUVERS ABOUT AIRLOCK EXTERIORS DURING SIMULATED WEIGHTLESSNESS

4.6.2.1 48" DIAMETER 6' LENGTH-CYLINDRICAL AIRLOCK GEOMETRY-TASK 5

This task consisted of the subject maneuvering from the exit bar to the tether line placed on the opposite end of the airlock and then returning to the exit bar. The first series of tests were performed with a handhold placed midway between the exit bar and tether. The handhold was omitted for the second series of tests. Figure 4.6.1 is a sequential representation showing this task performance.

Observation of subject performance indicated that the use of a tether line is better from a safety standpoint than the exit bar. One of the greatest deterents to successful completion of the maneuver was suit interaction with the airlock end panels. The Mark IV full pressure suit was designed for use primarily in a sitting position. Consequently, while relaxed at full pressure the suit assumes a modified sitting position. When the subject attempted to move past the end panels, his thighs hung-up on the panels. This was witnessed during both directions of travel.

This suit interaction had the greatest impact in the attempts to travel from the exit bar to the tether line. Because this type of maneuver involves the technique of "soaring," the subject had to keep clear of all appurtenances that could cause velocity and direction changes during the free soaring maneuver. The exit bar did not allow the subject to keep far enough from the side of the airlock to prevent his thighs from hooking on the end panels as they passed. This is a potential safety hazard. In one instance, the subject's thighs hit the end panel and caused him to float away.

In spite of this disadvantage, the exit bar offers an advantage over the tether line, velocity alignment. In attempting to pass from the tether line to the exit bar, the subject had great difficulty in aligning his velocity vector parallel to the axis of the airlock. On the final run of the series the subject was unable to reach the exit bar after repeated attempts.

The tether line offers two advantages; it is safer than the exit bar, and it gives the astronaut a second chance. When the subject attempted to maneuver from the exit bar to the tether line and floated away, he was "lost" and unable to come into contact with the airlock again. The tether line affords a second chance. The subject was always able to pull himself back and try again if he failed to reach the exit bar.

The use of the handhold midway between the end panels greatly reduced the problem of direction misalignment encountered without the handhold. In all cases, the subject was able to complete his transit from one end of the airlock to the other. However, difficulty was still experienced during the attempts to go from the exit bar to the handhold due to the subject's thighs hooking on the end panel.

Performance with and without the handhold indicates that a full length railing or tether line attached to both ends of the airlock be used. This would eliminate the necessity of an astronaut soaring from one place to another and greatly reduce the hazards involved. The subject performed two complete transits around the airlock circumference. The average velocity for transit was 0.95 feet per second.

4.6.2.2 SPHERICAL AIRLOCK GEOMETRY-TASK 19

This task consisted of the subject maneuvering about the exterior of the 7' diameter spherical airlock by means of the circumferential handrail provided. The handrail was composed of a 1" tubular section joined to the airlock at 6 equally spaced junctures along the circumference. The free hand height between the handrail and the surface of the airlock was 2.75 inches. The subject was required to approach the airlock exterior along the tether and make one complete transit around the airlock exterior using the handrails. At all times the subject was required to maintain contact with the handrail by at least one hand. Figure 4.6-2 shows the subject performing the transit maneuver while neutrally buoyant at 3.5 PSIG.

4.6.2.2.1 CIRCUMFERENTIAL TRANSIT - RUN 3

Elapsed Time: 0.0 Seconds

Subject begins maneuver outside the spherical airlock approximately 4' using the tether as a motion aid to approach the airlock.

Elapsed Time: 13.89 Seconds

Subject translates along tether in a hand-over-hand fashion, and after one abortive attempt grasps the lower section of the circumferential handrail with his left hand, his body inclined approximately 60° to the plane of the handrail.

Elapsed Time: 17.92 Seconds

Subject begins transit around airlock exterior by moving his left hand along the handrail till it is next to his right hand.

Elapsed Time: 31.82 Seconds

Subject continues to transit around the sphere traversing the = 180° section which is hidden from the camera view. As the subject emerges from behind sphere his body orientation is now aligned with the plane of the handrail.

Elapsed Time: 40.97 Seconds

Subject completes transit around spherical airlock circumference and pushes away from airlock along tether.

Elapsed Time: 68.02 Seconds

Subject returns to airlock exterior along tether.

Elapsed Time: 73.96 Seconds

Subject begins turnaround preparatory to making a transit around airlock in the reverse direction.

Elapsed Time: 89.73 Seconds

Second transit around airlock begins-subject aligned to plane of handrail.

Elapsed Time: 112.94 Seconds-End of Maneuver

4.6.2.2.2 USE OF THE HANDRAIL AS AN AID IN HATCH CLOSURE - RUN 1

Elapsed Time: 0.0 Seconds

Maneuver begins as subject exits outward opening circular hatch body inclined 60^{o} to circumferential handrail, left hand on handrail, right hand on sphere, over the place where separation.

Elapsed Time: 0.96 Seconds

Subject reaches out with right hand and grasps lower section of handrail-arms separated about 36", face close to visual access port, legs extended up and away from sphere.

Elapsed Time: 1.75 Seconds

Subject moves left hand along upper section of handrail and rotates body.

Elapsed Time: 3.74 Seconds

Subject reaches and grasps lower handrail with right hand, close to handrail connection point-rotating the sphere by this motion.

Elapsed Time: 4.58 Seconds

Subject moves left hand along handrail to position of right hand and releases right hand.

Elapsed Time: 20.30 Seconds

Subject retains contact with handrail by his right hand, closes the open hatch with left hand-applying needed torque-force with his right wrist and body.

Elapsed Time: 23.50 Seconds-End of Maneuver

4.6.3 WALKING AT SIMULATED 0.08, 0.16 G_e-TASK 17

4.6.3.1 DISCUSSION

The object of this task was to observe the manner in which a subject walked in a simulated .08 and .16 gravity environment provided by the water immersion technique.

The equipment and facilities used for this task were as follows:

a. Swimming pool with water at the deep end over 9 feet deep

b. Photographic equipment for underwater photography

c. A plastic grid with horizontal and vertical lines 12 inches apart as a background behind the subject.

d. One subject Navy Mark IV Mod 0 full pressure suit, pressurized to 3.5 PSI above the surrounding medium. The subject was weighted as described previously to simulate .08 and .16 gravity levels.

The subject made three runs at each of the above gravity levels. In making a run, the subject started at the right side of the grid described above, walked to the left side of the grid, turned around and walked back to the right side again. He made three runs at this gravity level.

In starting to walk at the .08 gravity level the subject leaned forward about 45° from the vertical. As he began to move, his body straightened up so the vertical angle varied from zero to about 30 degrees. During one run, the subject tried to move forward by pushing hard with first one leg and then the other, but this only resulted in his moving vertically so both feet were off the bottom. He had to wait until he settled down on the bottom again before taking another step. This routine did not seem to be very effective. Typical performance sequences are shown in Figure 4.6-3.

4.6.3.2 RESULTS

The results of this test demonstrated the ability of a full pressure suited astronaut to walk under reduced gravity conditions. At the 0.16 gravity level, the subject maintained an average velocity of 0.78 ft/sec. with a maximum velocity of 1.33 ft/sec. and a minimum velocity of 0.18 ft/sec. From the subject's comments and film analysis, there was no apparent difficulty maintaining traction. However, it was observed that as the subject approached the upper velocity limit, he would lose traction and the velocity would decrease. This was the situation at both gravity levels: an increase followed by a corresponding decrease in velocity.

At the 0.08 gravity level, the walking technique began to differ from the normal mode of walking. The decrease in gravity associated traction and the velocity dependent drag of the water became very important. These two factors were responsible for the following performance variances:

(1) The angle of lean increased from 30^{o} with respect to the vertical at 0.16 G to 35^{o} at 0.08 G.

(2) A larger velocity spread at the lower gravity level. The average velocity was 0.66 ft/sec with a minimum velocity of 0.04 ft/sec and a maximum of 2.1 ft/sec. When the upper velocity limit was approached the magnitude of the force exerted on the walking surface by the subject caused him to begin leaping from the surface at which point the drag of the water caused the velocity to drop to a minimum.

(3) An expressed feeling of frustration, not present in the 0.16 G tests, on the part of the subject during the performance of the tests.

4.6.4 PERSONNEL TRANSFER BETWEEN CONFIGURATIONS-TASK 21

4.6.4.1 PROCEDURES

To investigate the procedures and problems of transfer between configurations, the capsule configuration and spherical airlock described in Section 4.2.2 were used. The two configurations were connected by a taut 25 foot long safety tether line. The subject was required to egress the capsule, proceed along the safety tether to the spherical airlock and ingress the airlock. The return maneuver was to be performed in a reverse manner except that hatch closure of the capsule would not be performed due to the internal construction of the mock-up.

4.6.4.2 PERFORMANCE ANALYSIS - RUN 1

Elapsed Time: 0.0 Seconds

This task began with the subject standing in the capsule hatchway. The performance sequence is shown in Figure 4.6-4. Turning to his left to face the safety tether line, which was attached to the capsule between the doors, the subject grasped the tether with both hands and pulled himself free of the capsule.

Elapsed Time: 6.2 Seconds

The subject then proceeded for a distance of approximately 10 feet with the longitudinal axis of his body aligned parallel to the tether line.

Elapsed Time: 16.2 Seconds

At this point the subject performed a yaw maneuver to align himself perpendicular to the tether line and completed the transit maneuver. During the entire transit, the subject was able to maintain his grip on the tether with at least one hand.

Elapsed Time: 55.2 Seconds

Upon reaching the spherical airlock, the subject unlatched the hatch and pushed it open. Grasping the edges of the hatchway, he pulled himself into the airlock to execute a head-first (normal) ingress maneuver.

Elapsed Time: 91.0 Seconds

After completing his entry, the subject grasped the hatch and used it as a motion aid during his turnaround maneuver. After completing the turnaround, he closed and latched the hatch.

Elapsed Time: 103.6 Seconds

After unlatching the hatch and pushing it open, the subject performed his egress maneuver. The subject experienced a slight difficulty during the egress. He attempted to hold onto the door during his head-first exit. After egressing to his waist level, he had difficulty bending himself to get his legs through the hatch while still holding onto the hatch with his right hand. After completing the egress maneuver, he pulled the hatch closed and latched it.

Elapsed Time: 191.2 Seconds

Grasping the tether with both hands, the subject proceeded along the tether to the capsule. This maneuver was performed with the subject's body perpendicular to the tether line.

Elapsed Time: 233.2 Seconds

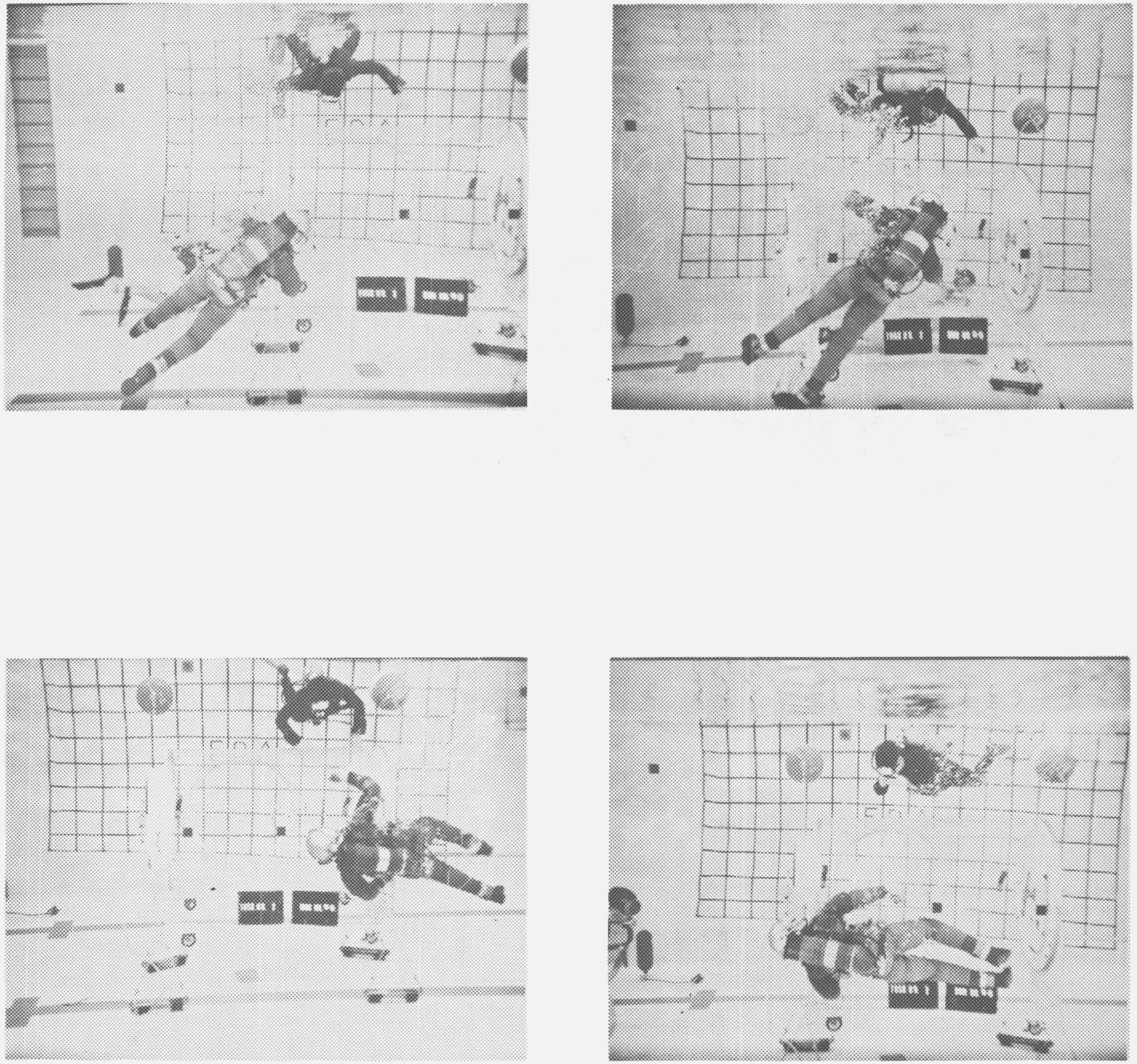
Upon reaching the capsule, the subject released hold on the tether with his right hand to align himself with the open hatch. Simultaneously he placed both feet through the hatchway. Assuming a slightly crouched position, he grasped the sides of the hatch opening and pulled himself into the capsule to complete the egress maneuver.

Elapsed Time: 255.0 Seconds-End of Maneuver

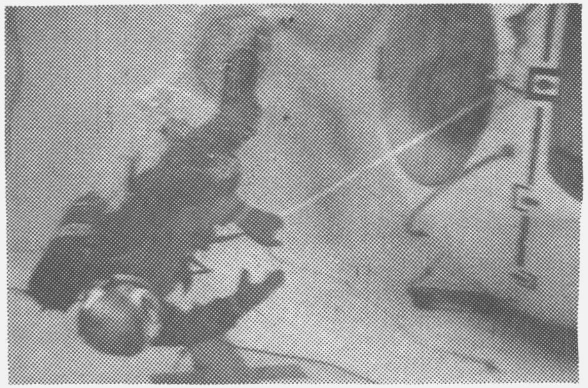
4.6.4.2 RESULTS

Test results revealed two points of interest during the task performance: The transit and the egress from the spherical configuration. During the beginning of the transit maneuver for a distance of 10 feet, the subject proceeded parallel to the tether line. He then rotated himself perpendicular to the tether for the remainder of the task. This was the result of restricted mobility and small field of view of the full pressure suit. The subject was unable to bend his head in the neck area of the suit in order to see where he was going. To compensate for this, he rotated himself until he was perpendicular to the safety tether. This allowed him to see his direction of travel during the transit maneuver.

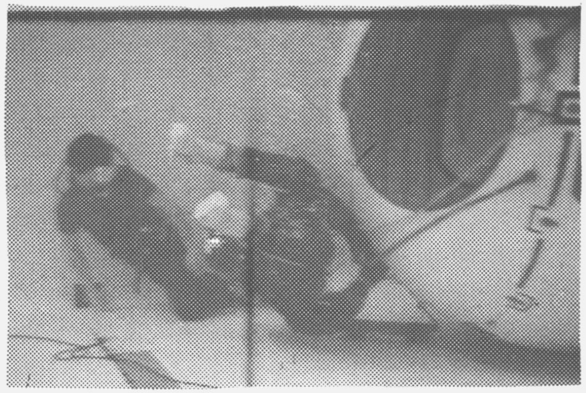
As stated in the performance analysis, the subject had difficulty performing his exit from the spherical configuration. This was the result of his attempts to maintain his hold on the door and close it while making an exit. In attempting to do so, he had difficulty getting his legs through the hatchway. This problem could have been eliminated by completing the egress maneuver before making an attempt to close the door. After completing the egress, the subject could have made a partial ingress to secure the hatch and pull it closed.



4.6-1 Sequence of Maneuvers About Cylindrical Airlock Exterior



(1)



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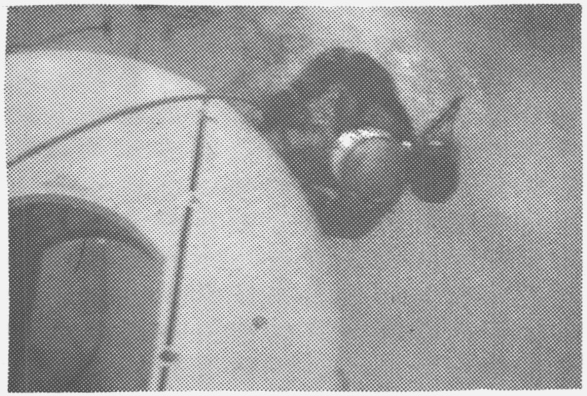
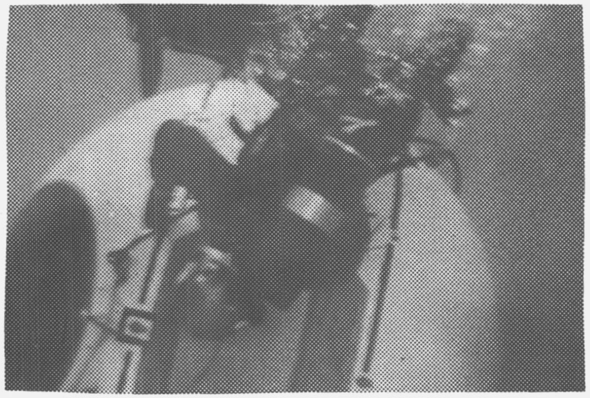
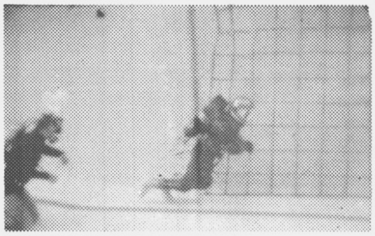


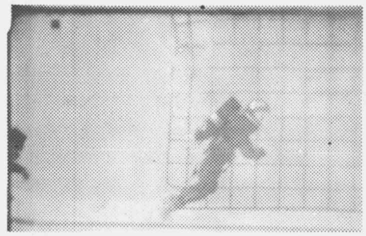
(3)



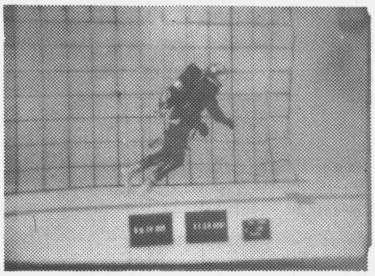
(4)

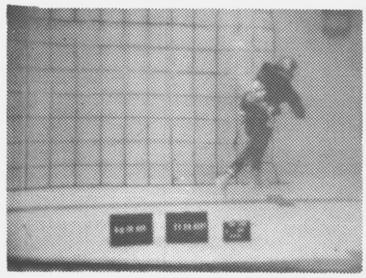
4.6-2 Sequence of Maneuvers About Spherical Airlock Exterior





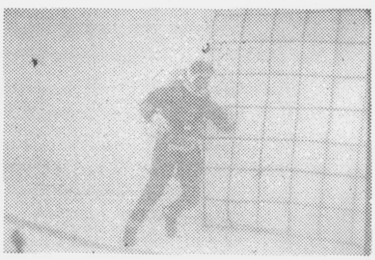
(1) (2)



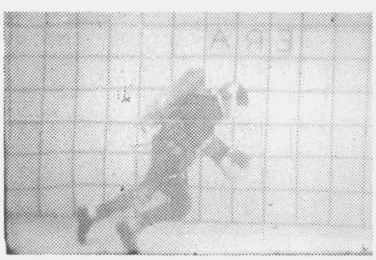


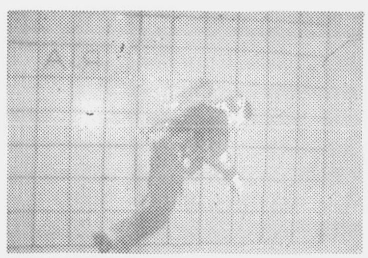
(3) (4)

Walking - 0.08 G



(1) (2)

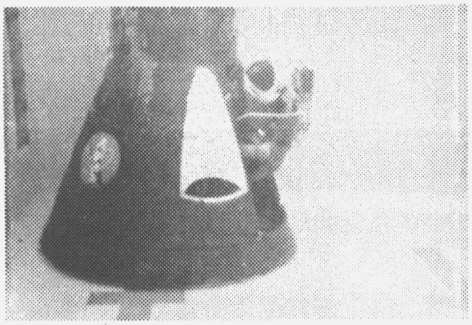


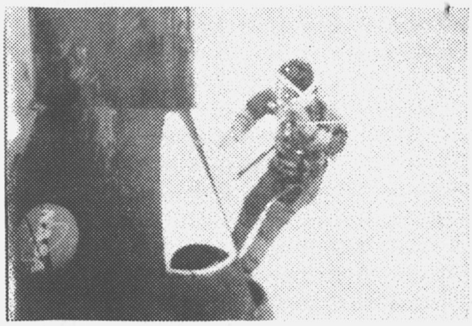


(3) (4)

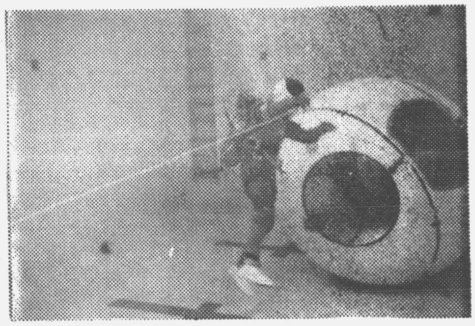
Walking - 0.16 G

4.6-3 Sequence of Walking at Simulated Reduced Gravity



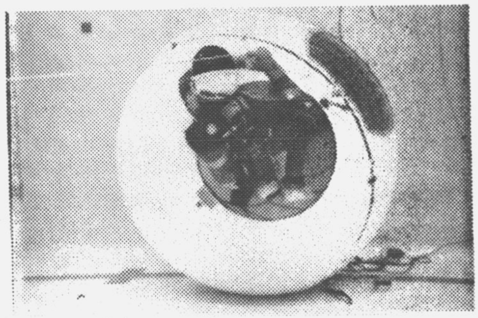


Egress Capsule

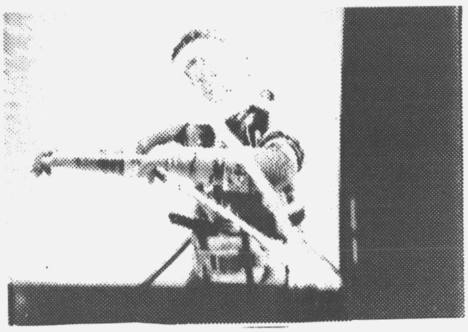


Transfer to Spherical Airlock

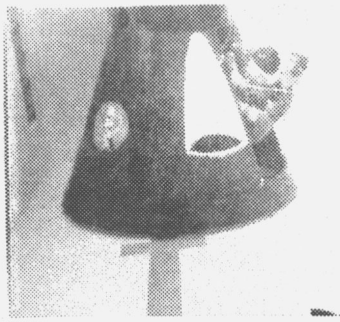
Ingress Spherical Airlock



Egress Spherical Airlock



Transfer to Capsule



Ingress Capsule

4.6-4 Sequence of Personnel Transfer Between Configuration

5.0 RECOMMENDATIONS

Water immersion simulation appears to be a very useful technique for studying quasi-static aspects of extravehicular tasks and intra-vehicular tasks requiring operation of pressure-suited astronauts. The limitations for quasi-static tasks arise as a result of drag induced by the viscous properties of the water medium. Preliminary studies/experiments at ERA have estimated the upper limit for velocity of operation at approximately 1.0 F/S to reduce the drag component of energy expenditure and to eliminate as much as possible planing effects due to non-symmetricity of the human body in the three major body axes. An experimental study is required to precisely investigate the effect of drag on subject performance for the water immersion mode. Such a study is now underway at NASA-LRC under contract NAS1-5875. The results of that effort should be applied to the NAS1-4059 to modify the results obtained in the water immersion simulation portion of this contract.

Initially, the contract effort under NAS1-4059 was intended to include a limited number of tasks-simulations to be performed in the USAF zero gravity research aircraft. Due to the scheduling of the Gemini tasks in the aircraft the Government was unable to supply the aircraft GFE to ERA for purposes of experiments under this contract, and the required tasks were discontinued. Cross-simulation of equivalent tasks in the zero gravity aircraft are, however, a very important source of data, necessary for the complete evaluation of the ingress-egress task performance. The zero gravity aircraft appears to be the only earth-based method for obtaining information on higher velocity-motion characteristics and physiologic inputs of the ingress-egress tasks. Further, such drag sensitive tasks as replenishment, rescue and exterior maneuvers require experiment-simulation performance in the aircraft. A program should be initiated to cross-correlate the data obtained by water immersion simulation with data obtained from zero gravity aircraft experiments on equivalent tasks.

When the contract NAS1-4059 was initiated, an attempt was made to investigate ingress-egress performance using a suit-system configuration representative of advanced state-of-the-art in extravehicular activities. The suit configuration chosen was an Arrowhead version of the Navy Mark IV-Mod 0 flight FPS, incorporating a back-mounted self-contained pressurization-breathing unit. The Arrowhead suit proved to be extremely mobile when pressurized to 3.5 PSIG, especially in the lower torso and leg area. Limited comparison with the Gemini G2C suit indicated that the upper torso-arm mobility were roughly equivalent but that the quasi-rigidity of the lower torso-leg portion of the G2C precluded direct comparative evaluation. A comparative evaluation of task performance with representative suit configurations should be incepted.

Current projection of future extravehicular operations appear to incorporate two distinct modes of operation; umbilical pressurization with a chest or back mounted pressurization unit and a completely self-contained back mounted unit capable of extended operations outside the spacecraft. Additional water immersion experimentation should be performed on the tasks accomplished during Phase III incorporating representative suit-system configurations.

The methods for analyzing ingress-egress performance relative to the task-hardware variations employed in this effort were task-time and limb angle-time measurements obtained by visual observation of continuous 16mm film records. These indicate the relative difficulty of the experimental variations but did not yield absolute information concerning energy expenditure for the performance of individual tasks. The combined evaluation of the area under the limb angle-time curves is related to the energy required for task performance but the constants relating this to energy expenditure are undetermined. It is recommended that additional effort be initiated to develop the experimental relationships of the limb-angle profile to energy expenditure. These relationships are also sensitive to the drag induced terms introduced above and must be investigated relative to drag as a parameter.

The development of adequate experimental measures of energy expenditure relative to water immersion simulation does not, however, solely depend on the evaluation of drag induced terms, particularly when the velocities of motion are not restricted to low levels. Orientation effects are also present, in that the limbs and torso not being internally subjected to weightlessness can add or subtract from the energy expenditure required for task performance. External encumberances, e.g. umbilical lines, instrumentation lines, can also add appreciably to the energy required for task performance.

Factors must be evaluated to determine the effects of mobility constraints and motion induced by pressure-gradient effects since the mean ambient pressure is adjudged relative to the waist level of the subject and the suit ΔP is regulated to this level. Therefore, the pressure differential is higher for the upper portions of the suit and lower for the lower portions of the suit, when the subject is in a vertical orientation.

This effect tends to magnify the motion excursions of the subject off the horizontal plane of operation. Suit mobility is also directly affected since the maximum pressure deviation is on the order of $\pm$ 1 PSI from nominal yielding an actual ΔP of = 4.5 PSI in the upper limbs and 2.5 PSI in the lower limbs. The effects of the depth sensitive pressure-gradient should be evaluated by cross correlation with mobility studies run on the suit at one gravity in a vacuum environment.

The ingress-egress tasks performed during this phase of the contract encompassed a spectrum of airlock lengths and diameters from 24" to 60" for the diameters 18" to 72" for the lengths. This spectrum of lengths and diameters should be extended to include airlock diameters up to 72" and lengths up to 15' to encompass the range of airlock sizes for projected missions. Further evaluation should be made of the effect on ingress-egress performance of internal appurtenances such as storage elements, control and operating panels. These same factors should be evaluated for the closely aligned tasks of rescue and replenishment.

The airlock ingress-egress operation performed to date has been substantially directed to one-man operations. Additional simulations-experiments should be performed to assess the advantages and disadvantages of ingress-egress operation of multi-man crews particularly two-man operations.

One of the most important extravehicular operations to be addressed in future missions is that of rescue of an extravehicular astronaut. One version of a rescue maneuver was investigated during this contract, that of externally retrieving an immobilized subject, inserting him into the airlock along with the rescuer. Various other versions of rescue are possible and might prove more efficient from a time or energy expenditure viewpoint. Effort should be expended toward developing optimum rescue techniques by varying ancillary equipment conditions and initial operating conditions and investigating the effects of the variance by means of water immersion simulation techniques.

The effort under this contract to determine the maximum torque capacity of suited subjects in simulated weightless environments produced very valuable data relative to the ability of subject to exercise maximum torque-forces in the 48" cylindrical airlock configurations employed. Further, a limited investigation of the effect of fixed torque level on the total angular travel of latches indicated interesting and useful results. This effort should be expanded to include the evaluation of the effects of different airlock geometries, latch and handhold configurations, subject placement and the variation of initial torque levels. Additional effort should be initiated to simulate actual hatch-latch torque operating profiles during hatch operation.

NASA-Langley, 1968 —— 5

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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